THE UNIVERSITY OF ALBERTA

THE RELATIONSHIP BETWEEN PERFORMANCE RATING, HEART RATE AND FORCE TIME CURVES FOR SELECTED TASKS

by

© VIJAY KUMAR AGARWAL

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES

IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE

OF MASTER OF SCIENCE

DEPARTMENT OF AGRICULTURAL ENGINEERING

EDMONTON, ALBERTA

SPRING, 1969

UNIVERSITY OF ALBERTA

FACULTY OF GRADUATE STUDIES

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies for acceptance, a thesis entitled "The Relationship Between Performance Rating, Heart Rate and Force Time Curves for Selected Tasks" submitted by Vijay Kumar Agarwal in partial fulfilment of the requirements for the degree of Master of Science.

ABSTRACT

The purpose of this study was a physiological investigation of performance rating (work study technique of work measurement) for two tasks. Another objective was to determine the suitability of a force platform as a measure of rating the performance of workers in relation to physiological cost of work.

The physiological method employed was the measurement of an individual's heart rate while working. Two tasks, hacksawing and grain shovelling, were performed. Two male subjects participated in the experiments. The bodily exerted forces of the subjects were measured by force platform while they performed their tasks.

A simple linear regression was carried out to determine correlation coefficients involving performance rating,heart rate and force platform measure (lb-second or lb.).

The heart rate was found to be linearly related to the performance rating and force readouts from the force platform. Within the limitation of the designed experiments,it was concluded that it is possible to compare two different tasks based on force platform readouts and heart rate more objectively than the presently employed method of rating the performance.

ACKNOWLEDGEMENT

I am deeply indebted to Professor T.A. Preston for his guidance and consideration during the entire course of this study. I am also grateful to Professor H.P. Harrison and Dr. F.V. MacHardy for their guidance in setting up the recording instruments graciously supplied by them. Sincere thanks to Miss E. Symons for her assistance in typing this thesis.

Financial support provided by grants from the MacGregor Smith Scholarship is acknowledged.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

FIGURE PAGE

CHAPTER I

I. INTRODUCTION

Technical progress has played an important role in the development of society. Machines have increased the productive capacity of man in practically all areas of human activity. However, in spite of this technical progress, the need of muscular work of man has not been eliminated from industry. The average man still produces mechanical energy in order to perform almost any operation. As a part of man's involvement with the modern technology, machines should be designed to fit the ergonomical need of the operator. The expression "machine" implies, as stated by Dejong (11), a material device that transmits the force or directs its application. In order to make the best use of a man-machine system associated with any task, it is essential to know the range and limitations of the man component in relation to the whole system. The range and limitations are factors like comfort, safety, and physiological factors like fatigue. Therefore to enhance the capabilities of man and to overcome his limitations, the physiological expenditure (cost) required of the worker must be considered in relation to the physical work. In the 19th century, Taylor, cited by Barnes (6), measured the physical work with the concept of horsepower and the time-study technique.

Since the turn of the century, interest in work physiology has increased with the practical objective of developing an effective methodology for measuring human physical work. Numerous experiments have been performed in order to determine the

physiological cost of muscular work of varying degrees. It is evident from the bibliography that several investigators have determined the physiological cost of performing various tasks such as walking, running, engaging in athletic activities, and farm work.

In the past 50 years, the number of studies in the area of work measurement have increased with the objective of perfecting the techniques for predicting the operator's performance and time needed of operators, engaged in different tasks under varying work loads. Perhaps the most important and most difficult part of work measurement is to evaluate the operator's performance. An operator's performance is his ability to utilise effectively all of his internal factors to produce output. The present method of estimating of operator's performance is called rating and is a matter of personal judgement of the work study practitioner. Therefore such personal judgement is open to personal biased errors. One recent development in physical work measurement has been the introduction of the force platform. In any man-machine activity the human body exerts force. The bodily exerted force depends upon the type of activity and physical environment. Study of the magnitude of such exerted force as measured by the force platform and corresponding physiological cost might yield comparable data about an individual's or group's rating performance. Such information may also lead to the solution of the problems concerning the evaluation of alternative work methods, the deduction of physiological cost

and work stresses and the economical assignment of workers to tasks compatible with their physiological capacity.

The purpose of these experiments was to make use of the force platform, as a means of measuring physical effort under various work loads and to investigate the interrelationships between force measurement, performance rating and heart rate.

The scope of the investigation did not include the study of the intra-individual differences between the subjects.

The specific objectives of the investigation were to relate:-

1. Heart rate and performance rating for the hacksawing and shovelling tasks.
2. Heart rate and composite force (pound-second) for the hacksawing and shovelling tasks.
3. Heart rate and average force (pounds) for hacksawing and shovelling tasks.

It is emphasized that it is not claimed that any relationships found in the data are relevant to the population at large, or that the statistical analysis is appropriate to more than the two subjects studied.

CHAPTER II

REVIEW OF LITERATURE

Research related to the use of force platforms as a work study tool has been very limited. Elliot (14) reviewed the literature concerned with the force platform and other force measuring devices and concluded that the major contribution of the force platform has been in the area of medical studies related to gait. Payne et al (28) and other investigators (31, 37) used the force platform in studies concerned with athletic activities. The following literature cited is related to the development of force platform, physiological methods of measuring work and physiological evaluation of the force platform.

I. FORCE PLATFORMS

Elftman (13), in 1938, build an instrument consisting of two platforms, a series of compression springs, ball bearings and recording levers. Any force exerted on the platform caused deflection in the recording levers. The deflections of the recording levers were photographed with a high speed camera to record the magnitude of the forces.

Lauru (21,22), in 1949, constructed a force platform incorporating piezoelectric quartz crystals which have the property of emitting a small electric voltage when subjected

to externally applied pressure. The platform used by Lauru had a triangular design consisting of two sections resting on quartz crystals. The top level rested on three crystals, one placed at each corner in order to measure the vertical components of exerted force. Two crystals mounted at the outer edges of the platform registered the frontal and the lateral forces. The electric impulses emitted by the crystals due to the applied pressure were amplified and recorded by means of an oscillograph.

Greene and Morris (18), in 1959, designed a force-platform based on a cantilever system. The top plate was of the shape of an equilateral triangle supported by a frame which in turn was supported at the corners by steel ball-bearings resting on cantilever beams. The forces developed by body movements in the beams resulted in deflections. These were transformed into electrical signals by means of sensing cells, called linear variable differential transformers (LVDT),and an oscillograph was employed to record the signals. The triangular design resolved any externally applied load into three orthogonal components.

Barany and Whetsal (3), in 1962, redesigned the original model constructed by Greene (18). The new redesigned unit had added features of compactness, portability and was comparatively inexpensive from the structural point of view. However, the new design maintained the geometric and mechanical properties of the original one. The device weighed less than one hundred

pounds, with overall dimensions of 25 inches x 22 inches x 5 inches. The redesigned force platform is capable of measuring the forces exerted by a subject while performing various types of work. It is sensitive enough to record the heart beat of motionless subjects.

Marks and Hirchberg (24), in 1964 used a force platform composed of two right angle triangular sections so as to form a square of forty inches. In a sense, the springs of Elftman's (13) design were replaced by cantilever beams, and the forces were transformed into electrical signals by means of strain gauges.

Barany (5), in 1964, used the Greene and Morris (16) force platform and redesigned it to fit into a tread mill. The purpose of this arrangement was to measure bodily forces exerted by subjects, with complaints such as hemiplegic gait, while walking on a tread mill and to develop a fast and simple data reduction system which would integrate accurately the force traces over time with respect to amplitude and direction.

II. PHYSIOLIGICAL METHODS OF MEASURING WORK

Passmore and Durin, cited by Barnes (7), wrote a physiological review, in 1955, of literature concerned with human energy expenditure in relation to physical work. Any physical work results in changes in oxygen consumption, heart rate, pulmonary ventilation, body temperature, lactic acid concentration

in blood and other factors. The changes in these physiological factors depend upon the intensity of work. There is a direct relation between oxygen consumption, heart rate, total pulmonary ventilation and physical work performed by an individual.

Brouha, cited by Barnes (6), in 1956, did extensive studies to classify work loads in terms of physiolobical reaction. He classified the work loads in wide ranges namely light, moderate heavy and very heavy ,and prepared the following table.

TABLE 1

CLASSIFICATION OF WORK LOADS IN TERMS OF PHYSIOLOGICAL REACTIONS

Work Loads	Energy Expenditure (Calories per minute)	Heart Rate During Work (Beats per minute)
Light	2.5 - 5.0	60 - 100
Moderate	5.0 - 7.5	100 - 125
Heavy	7.5 - 10.0	125 - 150
Very Heavy	10.0 - 12.5	150 - 175

From the numerical figures ,one could state that an average worker on any physical task could be expected to work at a performance level equivalent to 5 to 7.5 calories per minute and at a heart rate of 100 to 125 beats per minute without over-loading himself.

Dupis (12) in studying the effects of tractor operation on human stresses used pulse rate as an indication of stress.

Hodges and Esmay (19) determined human energy expenditure for handling baled straw. Indirect calormetry was used to measure the energy expended to compare human energy expenditure cost of different ways of handling baled straw.

Cotes and Meade (10) studied the dynamics of walking and derived a number of relationships between the various variables such as lift per step, lift per minute, work of lift per minute, gradient work per minute, metabolic energy expenditure, involved in walking. A particular relationship between energy expenditure and the square of the forward velocity while walking horizontally has been used to calculate the velocity of minimal expenditure per unit of horizontal distance moved.

Christensen (9), reviewing the physiology of work, stated that heavy or moderately heavy muscular work is a subject of physiological research and lighter repetitive work should be the subject of psychological research. Christensen in his study reported the beneficial effect of dividing heavy muscular work into short working periods followed by short pauses.

Poulsen and Asmussen (28) suggested that for short time measurements, oxygen uptake and heart rate are reliable for estimation of physiological energy requirements of certain jobs. The findings of several research workers suggests that while the direct measurement of oxygen uptake during work gives the most reliable results, it is on the other hand rather cumbersome for the subject to breath

through a mouth piece and to carry large bags or long tubes around with him. It may lead to errors in measurement of actual energy requirements of a certain job. Schertz (32) observed the encumbering influence of mask and meter and found that the ratio of picking rate of oranges with respiration meter to that without it, was 0.82 for picking fruits reachable only from a ladder. A straight line correlation was obtained by Poulsen and Asmussen (28) between the work calories as determined from heart rate in relation to calories determined from oxygen uptake for practical jobs performed while sitting or standing and some while walking.

Esmay and McGinty (15) measured the peak human stresses in and around a cattle farm and used pulse rate as an indication of stress.

Molbech and Asmussen (26) studied the relationship between energy demand and speed of work. The experimental tasks were (a) to move 1 Kg iron blocks while sitting and (b) to move 14 Kg boxes to a distance of 135 cm. apart at a height of 110 cm. It is concluded that, if the main part of the movement consisted of acceleration and deceleration,then,the energy can not be measured in terms of work done per unit time. For such a type of work, a straight line relationship was found between oxygen consumption and speed of work raised to the power 1.74 in the experiment of moving blocks and 1.65 in the experiment with moving boxes. A good linear relation was obtained between heart rate increase and speed of work for household jobs.

Wyndham, et al, (38) performed the experiments with Bantu subjects. In the study, the subjects stepped for 15 minutes on and off a 1 ft. high stool at each of 6, 12 and 24 steps per minute, and on and off a 1 1/4 ft high stool at 24 steps per minute. One aspect of the study shows that work rate expressed as foot pounds per minute has a straight line correlation with the oxygen consumption expressed in litres per minute.

Barnes (7) used the working heart rate and energy expenditure in calories per minute to show physiological changes for physical tasks of handling cartons in a shipping room at different speeds.

Wyndham, et al, (39) reported findings which reveals that there is a good agreement between the physiological measurement of energy expenditure and work study practitioner's rating (speed or tempo or pace) assessment of performance index. They concluded that there is an approximate linear relation between the energy expenditure (oxygen consumption in litres per minute) and performance index.

Booyens (8) Malhotra (23) Sharkey (33) and several others have shown that pulse rate can be used as a means of measuring human energy cost.

III. FORCE PLATFORM AND PHYSICAL TASKS

Lauru (21,22) in a report of his studies described the use of the triangular platform to show the relationship between the

force measurements of bodily movements and the measurement of physiological cost. He concluded that the more area under the reaction force traces was directly related to the physical effort required for any particular task.

Brouha, cited by Yoder, et al (40) made his studies in order to evaluate the triangular force platform in relation to the physiological methods of measuring human energy expenditure. He used the Laru platform and found a correlation coefficient of 0.83 between vertical force-time area and oxygen consumption. The experiment involved three subjects raising and lowering the arms at shoulder level to full extension above the head at three levels and at various speeds.

Greene (16,17) constructed a triangular platform featuring cantilever beams and linear variable differential transformers (LVDT). For a foot pedal task, this device yielded a significant correlation, as high as 0.79 between force-time recordings and oxygen consumption. In spite of the fact that the correlation coefficients were high, Greene was not convinced by these results. One of the main arguments in favour of not accepting the high correlation was that a force platform yields only continuous records of force and not distance, and hence the force platform can not alone measure work.

Yoder et al, (40) selected three tasks and divided these into three groups to evaluate the validity of force platform from a physiological point of view. The task groups were: one group for those tasks utilizing leg motion, one for arm motions and a

third for hand motions. Statistical methods were employed to specify those factors which produced significant effects upon the amount of force exerted and the energy expanded during the performance of an experimental task. The findings of these experiments were claimed to prove that a force platform provides a suitable means for measuring and predicting the physiological cost of work when the operator is performing rather moderate or heavy strenuous tasks.

Nadler (27),while discussing several other methods of measuring operator's performance, points out that a plot of forces developed by the body movements of the subject while the task or activity is being performed may be a measure of operator's performance. Such study of force could have greater practical application if a relationship could be found between the force and physiological energy units.

CHAPTER III

METHODS AND PROCEDURES

I. APPARATUS

The bodily forces exerted by the subjects, while executing any task, were obtained by means of a force platform incorporating recording equipment. An analog computer was used to amplify, sum and integrate the force traces. An ultra-violet recorder and a tape-recorder were employed to record the force exerted. A telemetring technique was used to obtain working heart rate.

Force Platform: The force platform used in this study is shown in Figure 1. It was an adaption of Lauru's (21,22) force platform and was constructed by Russell (30). It was made up of an all metal construction apart from the work surface which was of 3/4 inch plywood. The main frame work was of 1/2 inch angle iron sections. This frame, which was in the shape of an equilateral triangle, was supported at each of the three corners resting on strain gauges. These measured the vertical component of the force exerted. Two additional strain gauges were placed within the frame work to measure the exerted force component in the frontal direction. One strain gauge was built in to measure the force in the lateral direction (perpendicular to frontal direction in horizontal plane). The

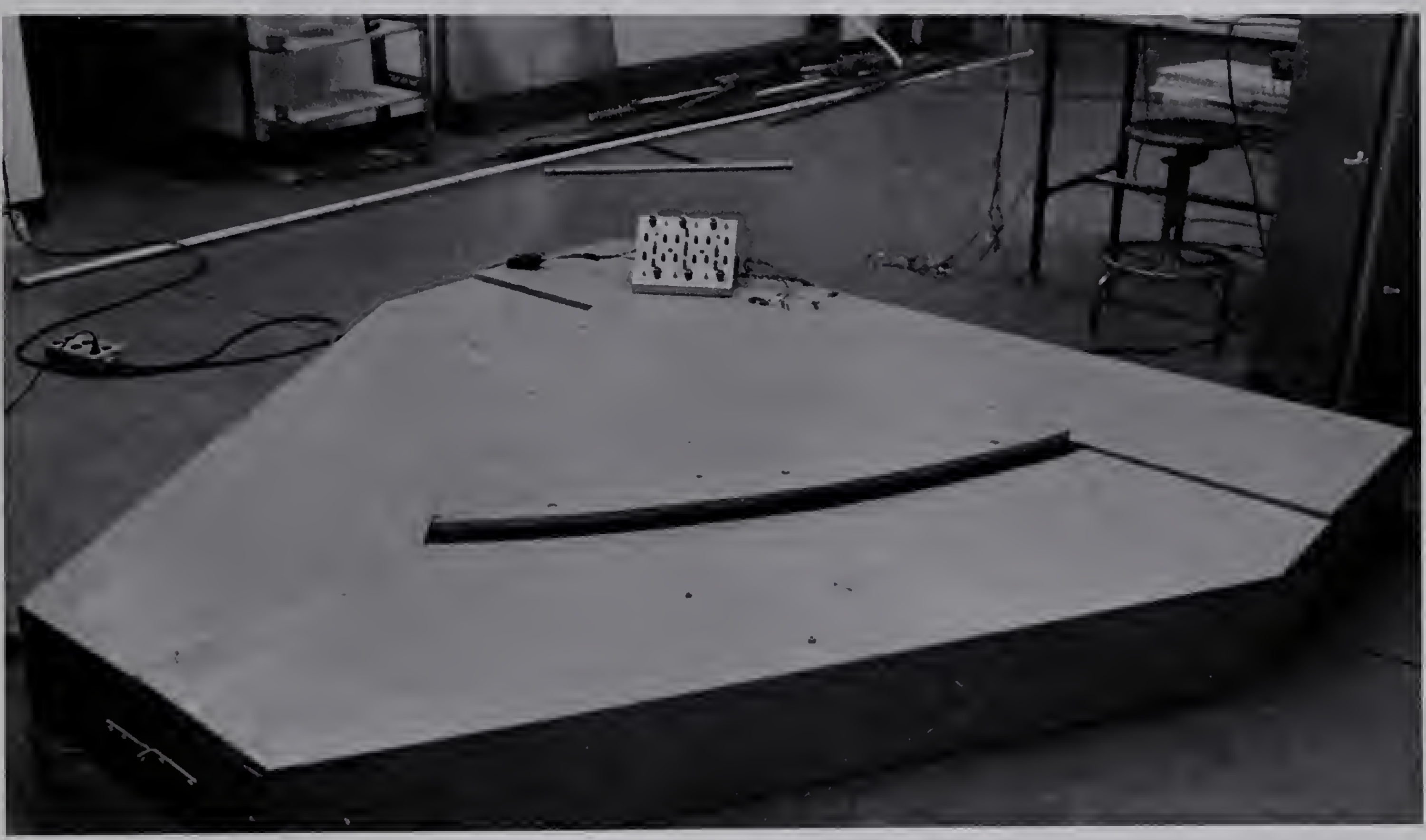


Figure 1: Force Platform.

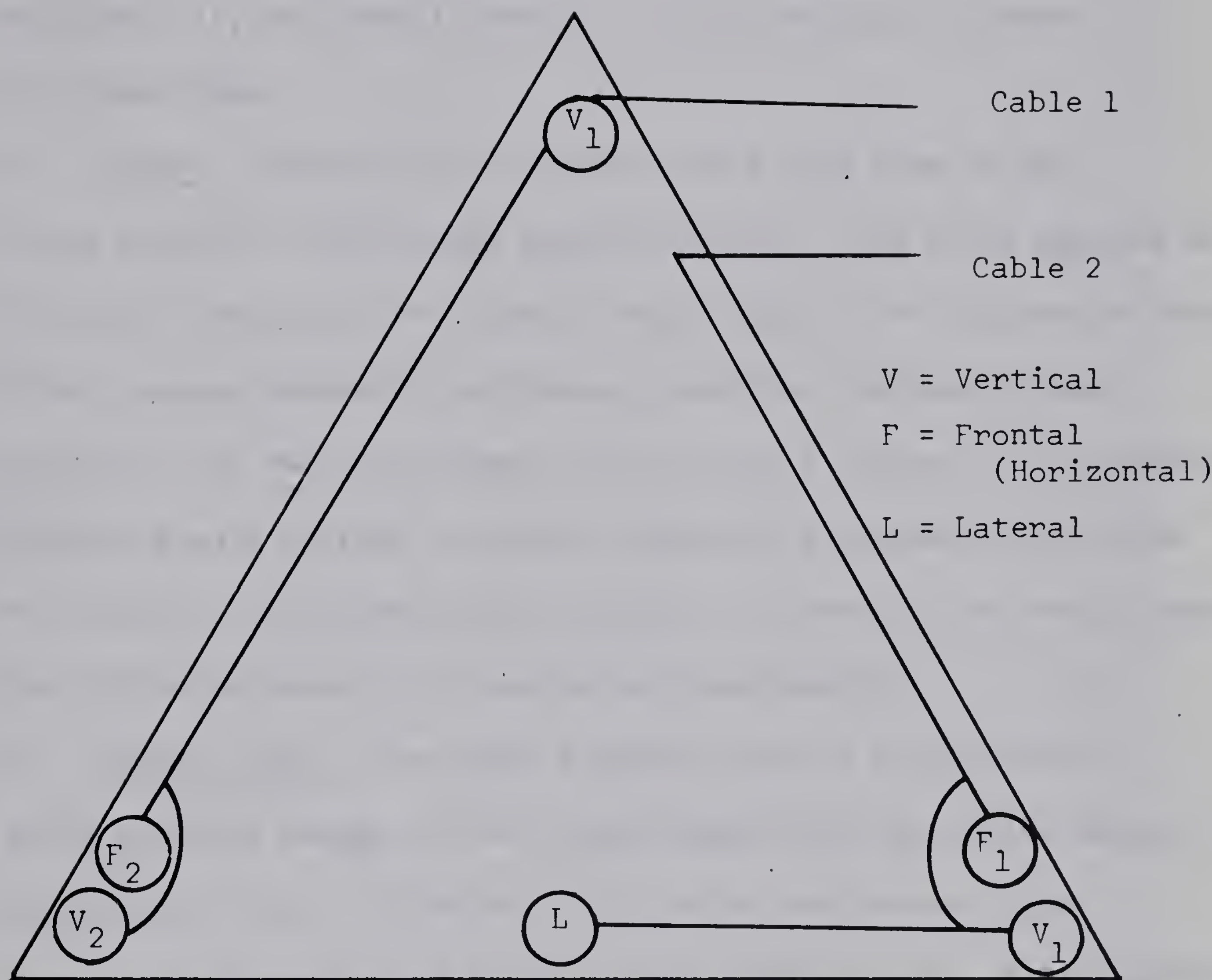


Figure 2: Schematic Diagram Showing Arrangement of Strain Gauges.

triangular design and the particular arrangement of strain gauges which is shown in Figure 2, allowed the measurement of three components of externally applied force in the vertical (V), horizontal frontal (F) and horizontal lateral (L) directions.

A. U-Bars: Transducers on U-bars are a main item of the force platform strain gauge measuring units. Any force applied at the top of the platform causes a deflection in the supporting U-bars. Strain gauges bonded to the U-bars transform the geometrical deflection of the main frame, due to applied forces, into electrical signals when a current is passed through the gauges; this is due to changes in the electrical resistance offered by the strain gauge for differing amounts of tension and compression.

B. Safety Stops: There was a safety stop on each U-bar to avoid possible damage of the strain gauges from excessive amounts of applied forces. These were of a screw and locknut type. They were adjustable and could be set, within limits, to accommodate the maximum force likely to be applied during an experiment.

C. Electrical Output: Strain gauges of 500 ohms were bonded to U-bars and wired into a Wheatstone bridge. The d.c. potential applied to the strain-gauge bridge networks was 5 volt. Each bridge was provided with an off-on switch and a balancing potentiometer. The switches and potentiometers were mounted on an aluminum circuit panel shown in Figure 3.

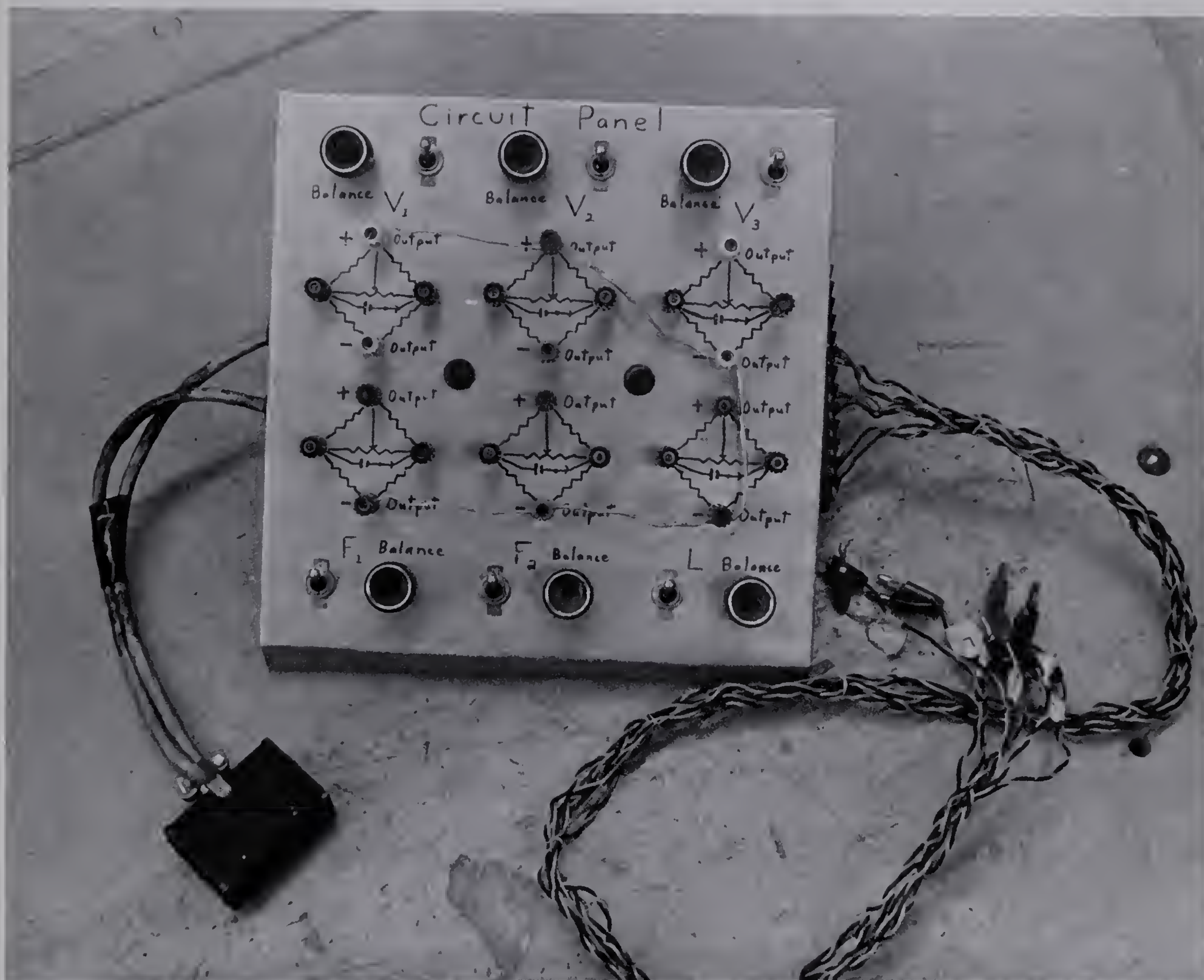


Figure 3: Circuit Panel.

Analog Computer: The analog computer was basically a self-contained instrument with a front panel to accommodate inputs and outputs of the operational amplifiers. It is illustrated in Figure 4. The unit used had ten operational amplifiers to sum and amplify the electric output (the out-of-balance potential) from the circuit panel.

Ultra-Violet Recorder: An ultra-violet recorder type SE. 3006, illustrated in Figure 5, was used to record force traces and heart beat signals while the manual tasks were being performed. Later, after the experiments, the recorder was also used to obtain paper graphs of the read out from the magnetic tape. The recording paper employed (Kodak, Linagraph Direct Print Paper, 6 in. x 125 ft) was light sensitive and was of direct print-out type which produced visible images when exposed to ultra-violet light and which required no processing. It did tend to fade, however, after a few weeks exposure. The main advantages of using the ultra-violet paper recorder were its high sensitivity, high frequency response and ruggedness. A built-in, photo-flash timing unit was used to mark the time intervals (0.1 minute) on recording paper. Functionally,

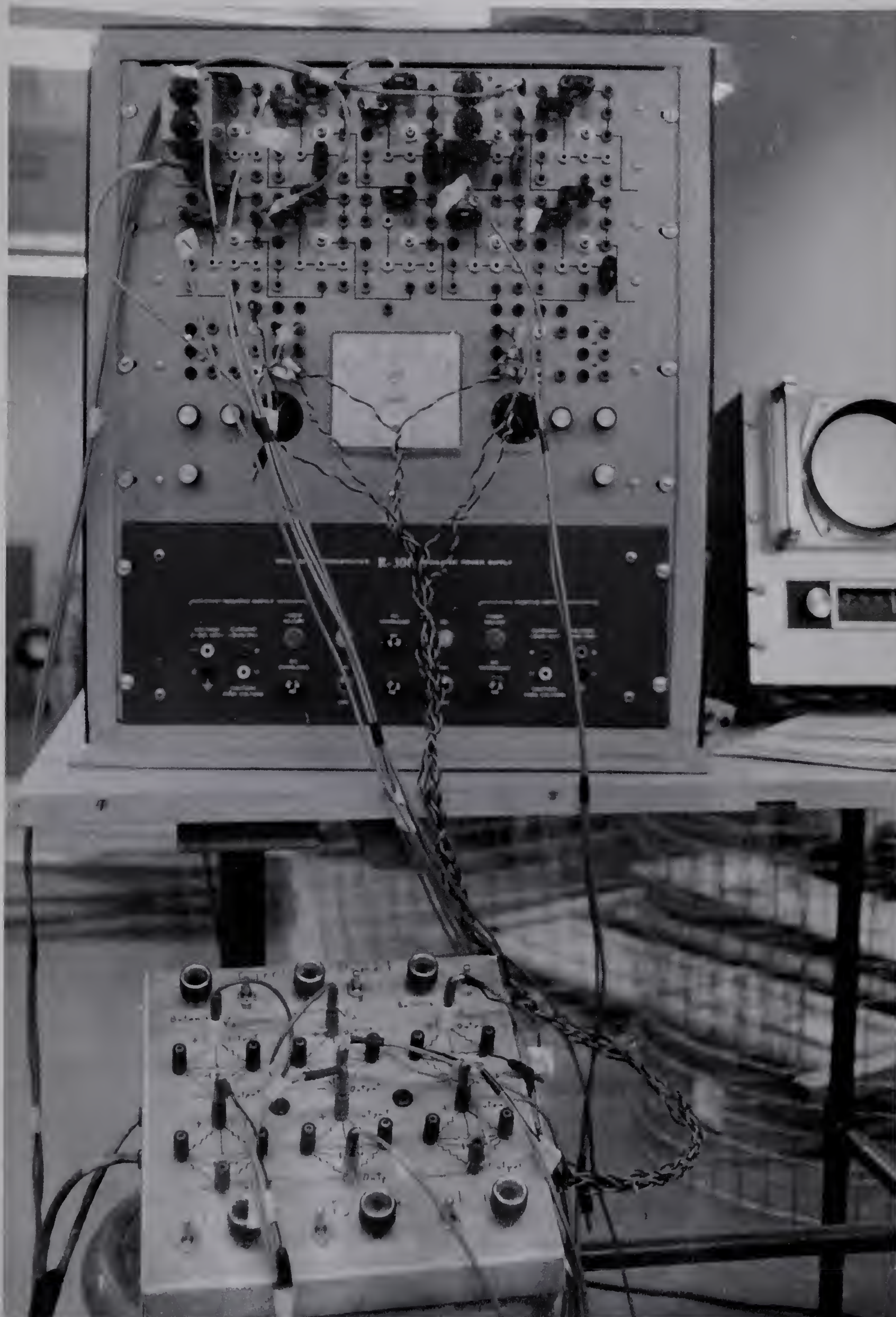


Figure 4: Analog Computer.

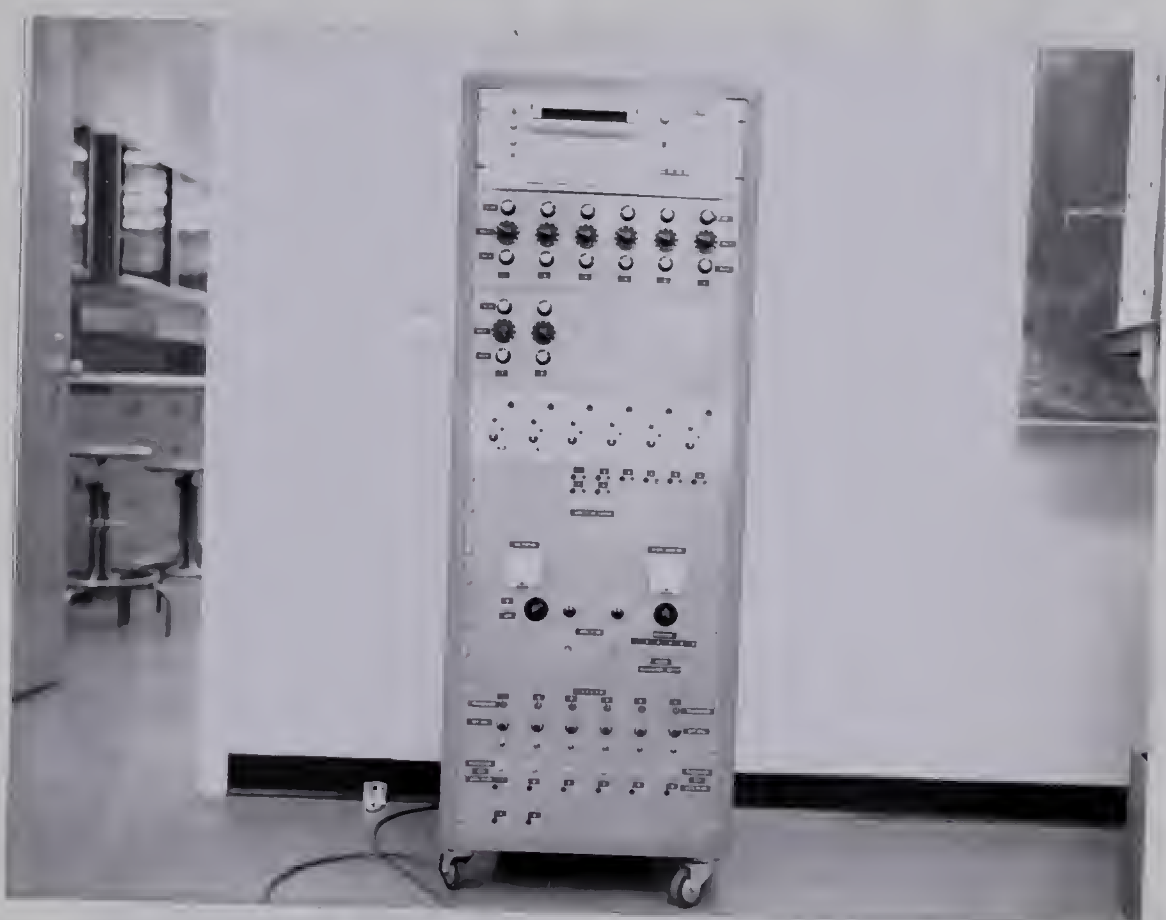


Figure 5: Ultra Violet Recorder

this timing unit initiated the pulses to a photo-flash tube which printed timing lines across the full width of recording paper at intervals selected by the panel mounted switch.

Magnetic Tape Recorder: Signals from the analog computer were recorded on a magnetic tape by a Sanborn-Ampex (model 2000) recorder shown in Figure 6. This recorder also had a voice channel which was used to record identification statements and relevant information pertaining to each of the experimental tasks.

Telemetering Technique: A telemeter is an electrical instrument for measuring a quantity, transmitting the results to a distance station, and then indicating or recording the quantity measured. A telemetry radio transmitting and receiving unit as applied to the heart function was used to gain accurate information of the subject's heart rate during work and at rest. It is shown in Figure 7. The frequency of the transmitter was set on the 92.8 mc/s band. The output from the receiver unit was recorded on to the ultra-violet recorder.

Figure 6: Magnetic Tape Recorder.

Figure 7: Telemeter (Receiver)

Instrumentation and Operational Summary for Recording Forces:

The force platform was set up to enable the subject's physical effort to be recorded accurately in the orthogonal directions (vertical, frontal and lateral). Transducers used to determine these forces were linked via a circuit panel (Figure 3) to the analog computer for amplification and summation. From the analog computer simultaneous recordings were logged, during each test run, on (a) the ultra-violet recorder and (b) the magnetic tape recorder.

Vertical force was measured at each of the three corners of the triangular force platform. For convenience these three vertical components were labelled V_1, V_2, and V_3. These components are represented schematically in Figure 3. Each component was equally amplified by approximately 33 times and then summed by the analog computer to give the effective vertical component of force exerted. One of these forces (V_1) was passed through a fixed 30K resistance while the other two (V_2 and V_3) were passed through each of two 100K potentiometers (variable resistances). By placing known weights of 100 lb. and 50 lb. on the platform, the potentiometers were adjusted so as to provide a summation of $V_1 + V_2 + V_3$ equal to the known weight being used, wherever the weight was placed within the triangle V_1 V_2, V_3 on the triangular force platform. Hence a 100 lb. weight, no matter where it was positioned on the triangular surface of the platform always caused the same voltage output to be produced from the

analog computer. These same known weights were used to produce datum reference points on the ultra-violet trace paper and magnetic tape. A 150 lb. weight produced a voltage output of approximately 2 volts, other weights gave directly proportional voltage outputs. The frontal forces, labelled F1 and F2, were also amplified and summed in the same manner as the vertical forces. In adjusting F1 and F2, a horizontal force was applied by spring balance. The F1 input to the computer was passed through a fixed resistance of 30K, while the F2 input was passed through a 10K potentiometer. F2 impulse amplification was then matched with the impulse F1 for any given load. The lateral force measured by one transducer was directly amplified and recorded. A schematic diagram of amplification and summation circuit is given in Appendix A. Due to the amplifying and summing functions carried out by the computer, it was found necessary to use only three recording channels on the ultra-violet recorder and the magnetic tape recorder to record the vertical, frontal and lateral forces.

Upon completion of each test, the tape was played back to reproduce the stored data for additional processing.

<u>Instrumentation and Operational Summary of Heart Rate Recording</u>:

The Metretel 1000 system, used in this study to detect heart beats, was a simple commercial unit requiring little technical skill to operate. The transmitter of the telemetry system was prepared for use by connecting to a battery, the voltage of

which was checked to insure that it was adequate to meet requirements. The transmitter was housed in a pocket of a leather belt fastened around the waist of the subject. The receiver was tuned to 92.8 mc/s band. This fine tuning is achieved by setting the needle pointer on the receiver tuning dial. Electrodes of type 1120 were thoroughly cleaned and a small amount of electrode jelly was placed in each cup of electrodes. Electrodes were then fixed to the subject's chest by means of surgical adhesive tape. A medical advisor supervised the correct placement of electrodes in relation to the subject's heart and checked their operation during the test. After the electrodes had been attached to the subject as described, they were attached to a transmitter. Each time the heart beats, a small electric potential is generated. This potential was picked up by the transmitter and transmitted to the receiving unit. One of the outputs of the receiver was connected to the input of the ultra-violet recorder to record the heart-beat signals.

Experimental Tasks: Two tasks were selected for investigation (1) hacksawing and (2) grain shovelling. Each task was designed to fit the ergonomic requirements of the two available subjects.

The hacksawing task was designed for the study of repetitive push-pull (friction-controlled) work pattern. It

required, in a sense, more arm movements than the shovelling task. It consisted of cutting a 3/8 inch square steel bar with the hand hacksaw. A new blade was used for each test. A work bench was fixed to the force platform and a small vice anchored to it. This was provided to perform tasks on work-surfaces located approximately 36" above the top surface of the force platform.

The shovelling task consisted of shovelling wheat with two different-sized shovels selected to demonstrate Taylor's classical task cited by Barnes (6). The grain was lifted approximately three feet (vertically) from the platform surface and was thrown away (horizontally) approximately three feet from the subject. The shovel sizes as determined by the average weight of wheat held by each were classed as 15 pounds and 20 pounds respectively. A wooden chute was so constructed that, when the wheat was shovelled, grains were deflected to their original position.

METHOD OF INVESTIGATION

Before each testing session, the force platform, circuit panel, analog computer and magnetic tape recorder were wired up to amplify, sum and record three orthogonal components of any external applied force on the force platform. The arrangement of force platform and recording apparatus is shown in Figure 8. After a warm-up period of half an hour, the amplifiers of the analog computer were checked for zero output when there was no input to them. The strain gauge bridge circuits

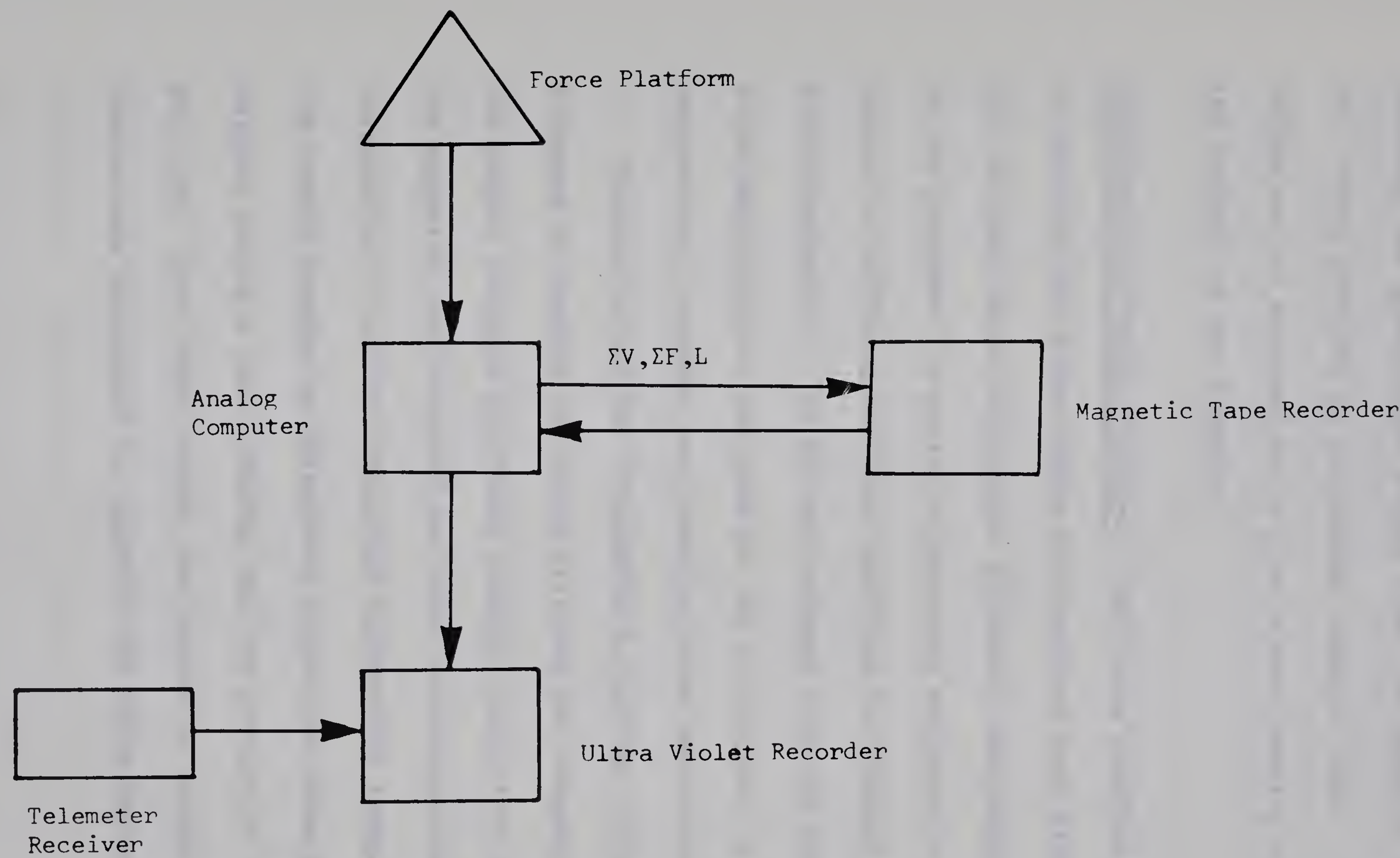
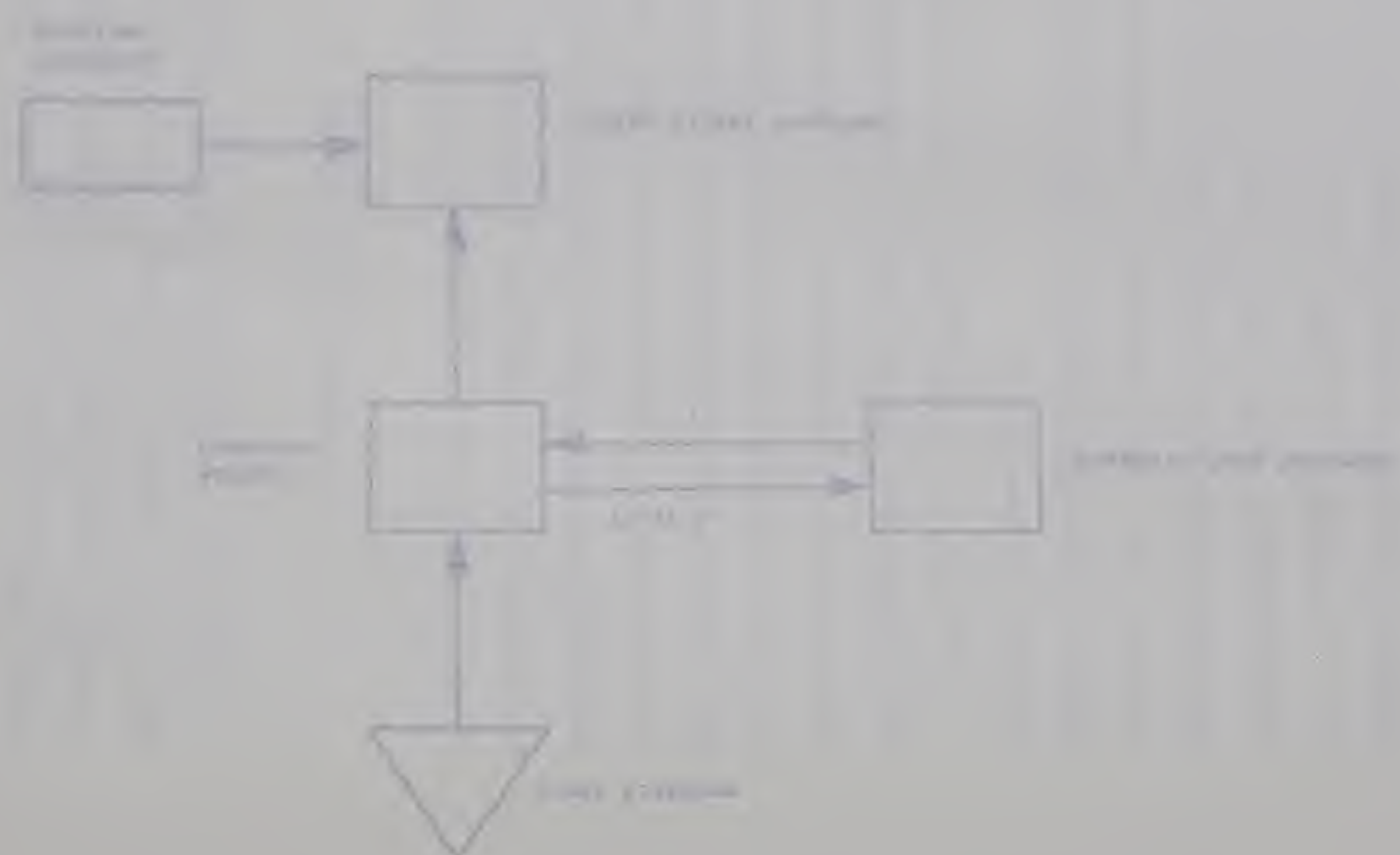


Figure 8: Schematic Diagram of Recording Instruments.



then were balanced by switching on their power supplies and checking the appropriate output from the computer with the volt meter provided on the analog computer panel. Each bridge was so balanced as to give a zero reading without any subject on the platform.

Calibration of Force Platform: The force platform was calibrated to quantify the force-traces obtained for each different task. For vertical force calibration different dead-weights were placed on the platform. A spring balance was employed to load the strain gauges to calibrate the force platform for frontal and lateral force components. The out-put voltage from the transducers after amplification was read on the volt-meter. A directly proportional relation was found in force and out-put voltage.

Calibration of the integrated force-time curves were achieved by loading the force platform for several seconds. The output voltages for these loadings were first recorded on the magnetic tape recorder and were later reporduced for integration to obtain integrated calibration force-time curves. The levels reached by integrated curves for these known weights during a time interval are the product of force and time. From these levels, the scales of integrated forces were determined to quantify the force traces of the tasks.

them were balanced by [illegible] no-load [illegible] on checking the linearities, [illegible] with the [illegible] from the unit meter [illegible] on the [illegible]. Then [illegible] was so balanced as to give a zero reading [illegible] any [illegible] on the platform.

<u>Calibration of Force Platform</u>. The force platform was calibrated to quantify the [illegible] different times. The vertical force [illegible] were [illegible] on the platform. A [illegible] method was employed to find the [illegible] to calibrate the force platform for [illegible] and [illegible] force components. The [illegible] voltage [illegible] was used as the [illegible]. A [illegible] proportional relation was found [illegible] force and [illegible] voltage.

Calibration of the integrating [illegible] were performed by [illegible] the force platform [illegible]. The [illegible] for these [illegible] were first [illegible] the magnetic tape [illegible] were [illegible] the integration [illegible]. The [illegible] during the [illegible] weights during a time interval and the product of force and time. From these curves, the [illegible] integration [illegible] were [illegible] to quantify the [illegible] of the [illegible].

Rating Technique As A Measure Of Progression Of Work:

Study of the progression of work throughout the test was carried out by the time study technique termed as rating. Rating is a procedure for measuring a subject's performance while working at different paces. Performance rating is defined as the mental comparison by a work study engineer of the subject's performance for a given method with the observer's own concept of normal performance. The level with which it is compared is termed normal performance ((BS.3131:1959)34013)*. Normal performance of work is the working rate of an average worker (under supervision) but without any incentive plan. This system of rating takes care of speed or tempo factor affecting the operator's performance. Carrol, cited by Nadler (27), Barnes (6) and Presgrave, cited by Nadler (27) suggested that the effect of all factors affecting the operator can be studied very well by observing the speed of performance and speed can be estimated to an extent by all the time study practitioners. The rating factor may be expressed in percentage or in points. The different rating scales commonly in use are shown in Figure 9 (6). In this study 100/133 system of performance rating has been used. In this system of rating, 100 on a rating scale equals the normal performance. While using this scale, it is expected by definition that the average incentive pace or tempo will fall in the range of 130 to 135 on the 100/133 scale A as on Figure 9. The maximum rating on this scale which might

---

* British Standard.

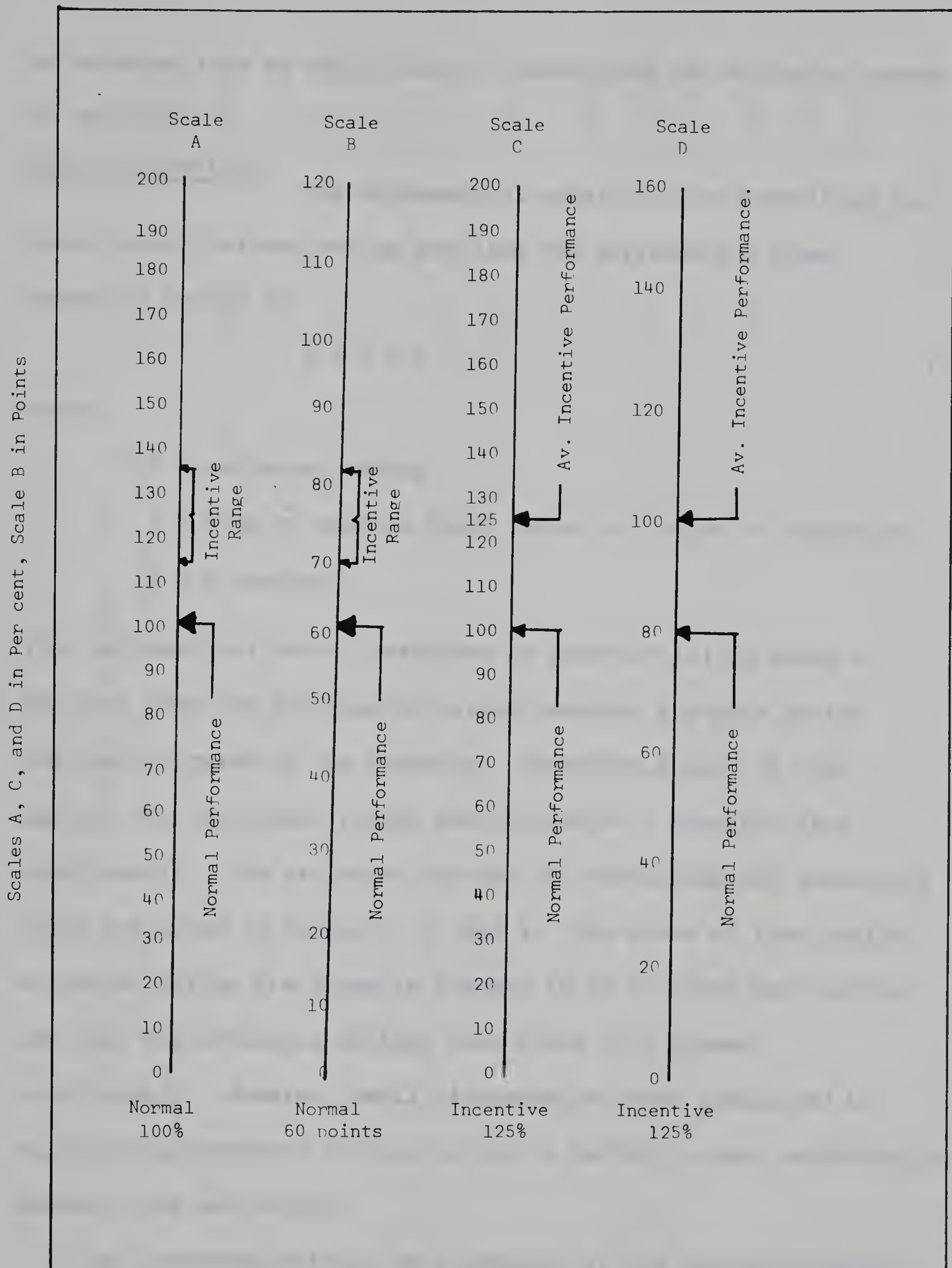
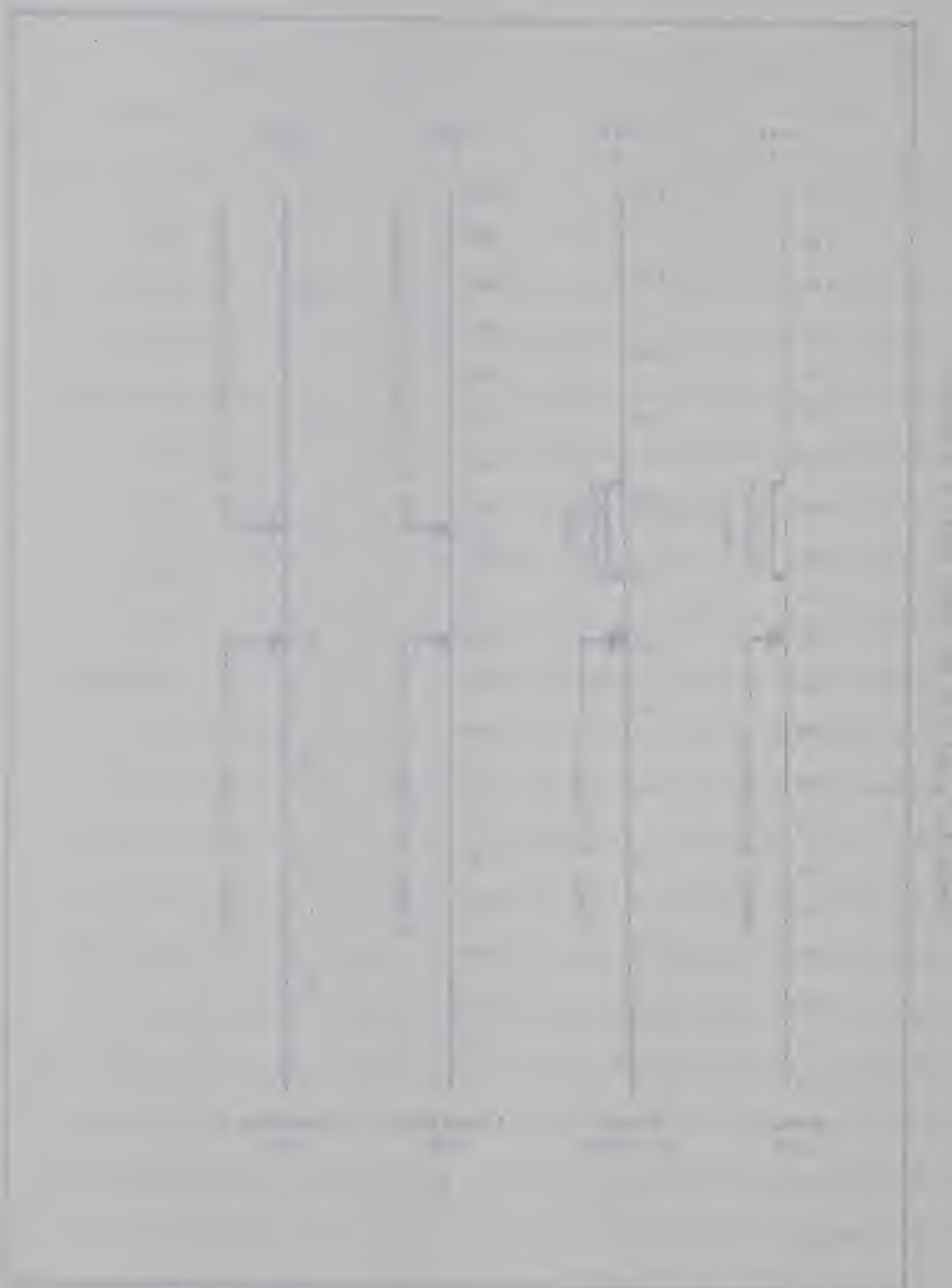


Figure 9: Rating Scales.



be expected from an exceptionally industrious and motivated person is about 200.

Rating Correction: The mathematical model(27) for describing the relationship between rating and time for performing a fixed number of cycles is

$$R \times T = K \qquad (1)$$

where,

R = estimated rating

T = time to perform fixed number of cycles of operation

K = a constant.

This mathematical model, described by equation (1), is based on the fact that the performance rating measures a simple factor and that is speed of the operator. Therefore, a plot of time against the reciprocal rating should provide a straight line relationship. The estimated ratings for hacksawing and shovelling tasks are given in Tables 2, 3, and 4. The plots of time against estimated rating are shown in Figures 10 to 15. For each subject and task the estimated ratings were close to a linear relationship. However, small discrepancies were eliminated by calculating corrected ratings to give a perfect linear relationship between time and rating.

The corrected ratings were obtained by the following method:

For every subject and each task, the constant K from equation (1) was calculated for each of the observed ratings and corresponding time cycle. The arithmetic mean of these K values

TABLE 2 .

RATING CORRECTION FOR HACKSAWING TASK .

	Test No.	Estimated Rating	Average Time For 10 Cycles in Minutes	$\frac{K}{100}$	Corrected* Rating	$\frac{1}{\text{Estimated Rating}}$	$\frac{1}{\text{Corrected Rating}}$
Subject No. 1							
	1	80	0.17	0.136	69.00	0.0125	0.0142
	2	85	0.14	0.119	83.90	0.0117	0.1192
	3	100	0.13	0.130	90.40	0.0100	0.1107
	4	110	0.10	0.110	117.30	0.0090	0.0085
	5	130	0.08	0.104	147.00	0.0007	0.0068
	6	150	0.07	0.105	168.00	0.0066	0.0060
Subject No. 2							
	1	45	0.33	0.148	40.70	0.0220	0.0248
	2	70	0.20	0.140	67.20	0.0143	0.0150
	3	100	0.14	0.140	96.00	0.0100	0.0107
	4	110	0.13	0.143	103.30	0.0091	0.0094
	5	130	0.09	0.117	149.30	0.0077	0.0073
	6	150	0.08	0.120	168.00	0.0066	0.0062

$$^{*}\text{Corrected Rating} = \frac{\text{Arithmetic mean of } (K/100)}{\text{Average Time for 10 Cycles in Minutes}} \times 100$$

TABLE 3.

RATING CORRECTION FOR SHOVELLING TASK.
(Shovel Size - 15 lb)

	Test No.	Estimated Rating	Average Time For 10 Cycles in Minutes	$\frac{K}{100}$	Corrected* Rating	$\frac{1}{\text{Estimated Rating}}$	$\frac{1}{\text{Corrected Rating}}$
Subject No. 1							
	1	60	0.66	0.396	62.50	0.0167	0.0160
	2	95	0.47	0.446	88.00	0.0105	0.0114
	3	110	0.37	0.407	112.00	0.0090	0.0088
	4	145	0.30	0.435	138.00	0.0069	0.0072
	5	160	0.25	0.400	166.00	0.0062	0.0060
	6	190	0.21	0.400	197.00	0.0053	0.0051
Subject No. 2							
	1	60	0.71	0.426	59.50	0.0166	0.0168
	2	90	0.50	0.450	84.50	0.0111	0.0118
	3	115	0.40	0.460	105.80	0.0087	0.0094
	4	140	0.31	0.434	136.20	0.0071	0.0073
	5	160	0.25	0.400	169.00	0.0062	0.0059
	6	175	0.21	0.368	201.00	0.0057	0.0049

*

$$\text{Corrected Rating} = \frac{\text{Arithmetic mean of } (K/100)}{\text{Average Time for 10 Cycles in Minutes}} \times 100$$

TABLE 4.

RATING CORRECTION FOR SHOVELLING TASK.
(Shovel Size - 20 lb)

	Test No.	Estimated Rating	Average Time For 10 Cycles in Minutes	$\frac{K}{100}$	Corrected* Rating	$\frac{1}{\text{Estimated Rating}}$	$\frac{1}{\text{Corrected Rating}}$
Subject No. 1							
	1	60	1.00	0.600	56.20	0.0166	0.0178
	2	85	0.71	0.605	79.00	0.0117	0.1260
	3	110	0.50	0.550	113.00	0.0091	0.0088
	4	140	0.38	0.532	148.00	0.0071	0.0067
	5	160	0.33	0.529	170.20	0.0062	0.0058
	6	180	0.31	0.558	181.20	0.0055	0.0055
Subject No. 2							
	1	70	1.00	0.700	61.06	0.0143	0.0163
	2	90	0.77	0.693	79.40	0.0110	0.0126
	3	120	0.45	0.540	135.80	0.0083	0.0074
	4	145	0.40	0.580	152.50	0.0069	0.0065
	5	180	0.30	0.540	200.56	0.0055	0.0049

*

$$\text{Corrected Rating} = \frac{\text{Arithmetic mean of } (K/100)}{\text{Average Time for 10 Cycles in Minutes}} \times 100$$

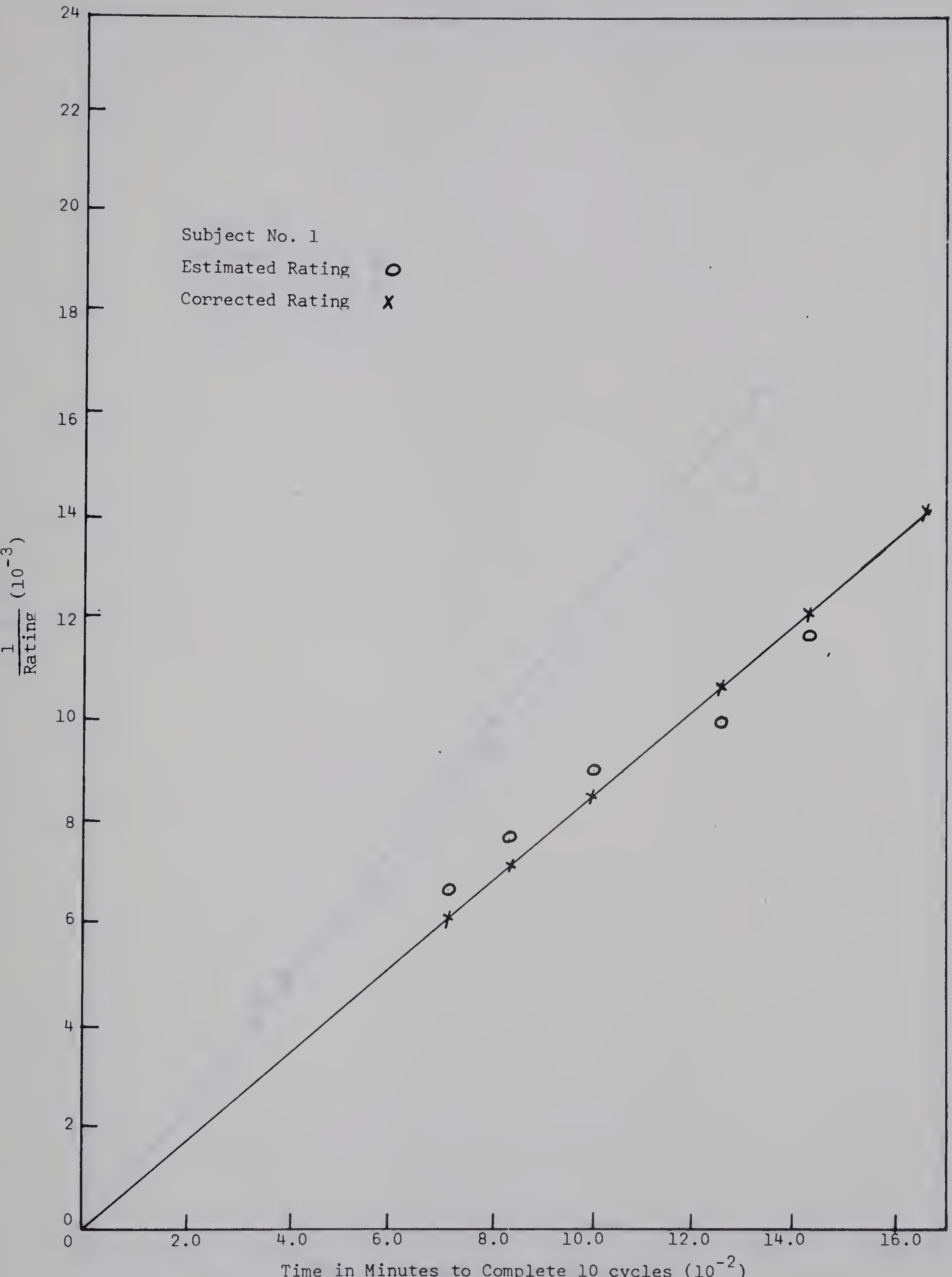


Figure 10: Reciprocal Rating Curve for Hacksawing Task.

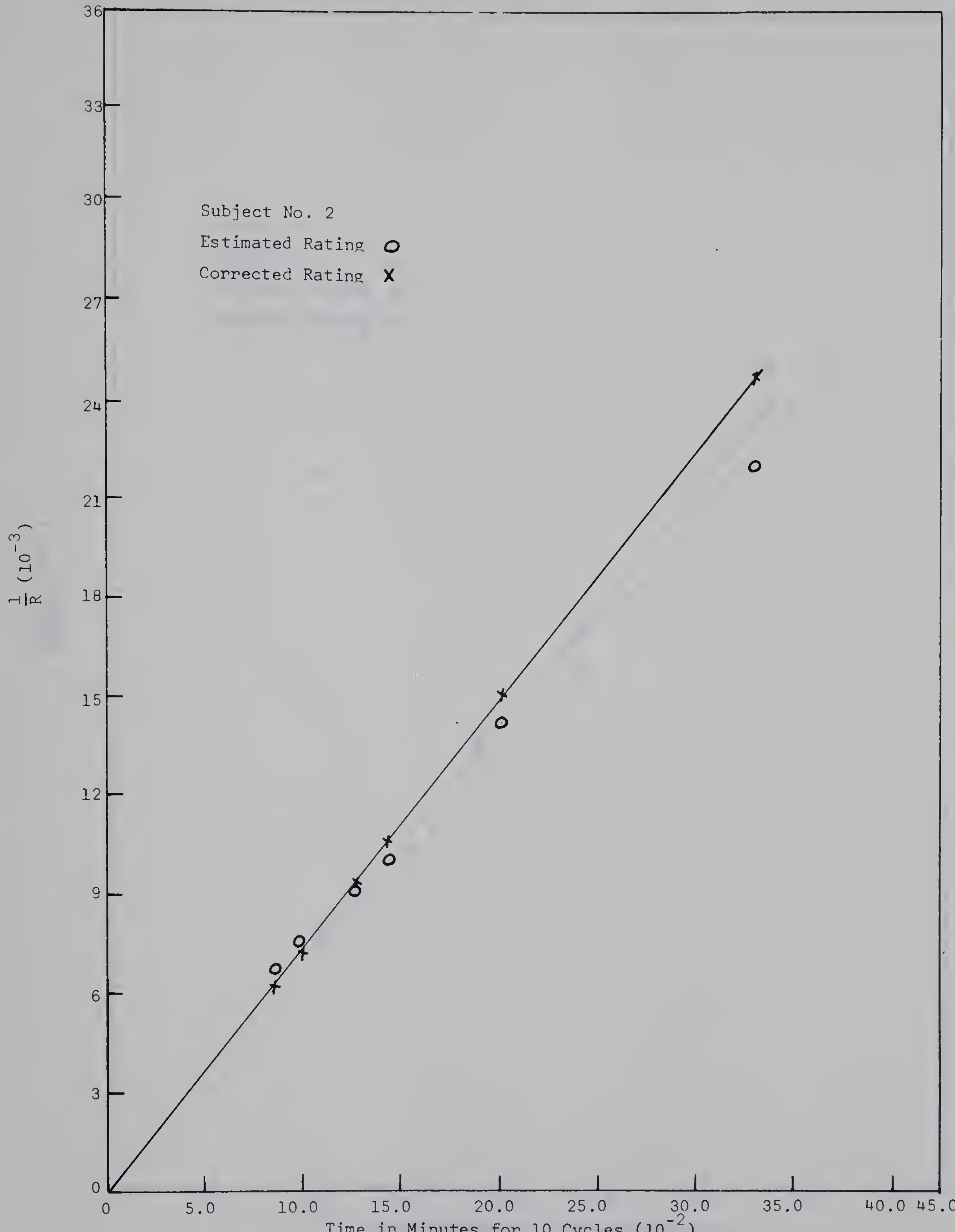
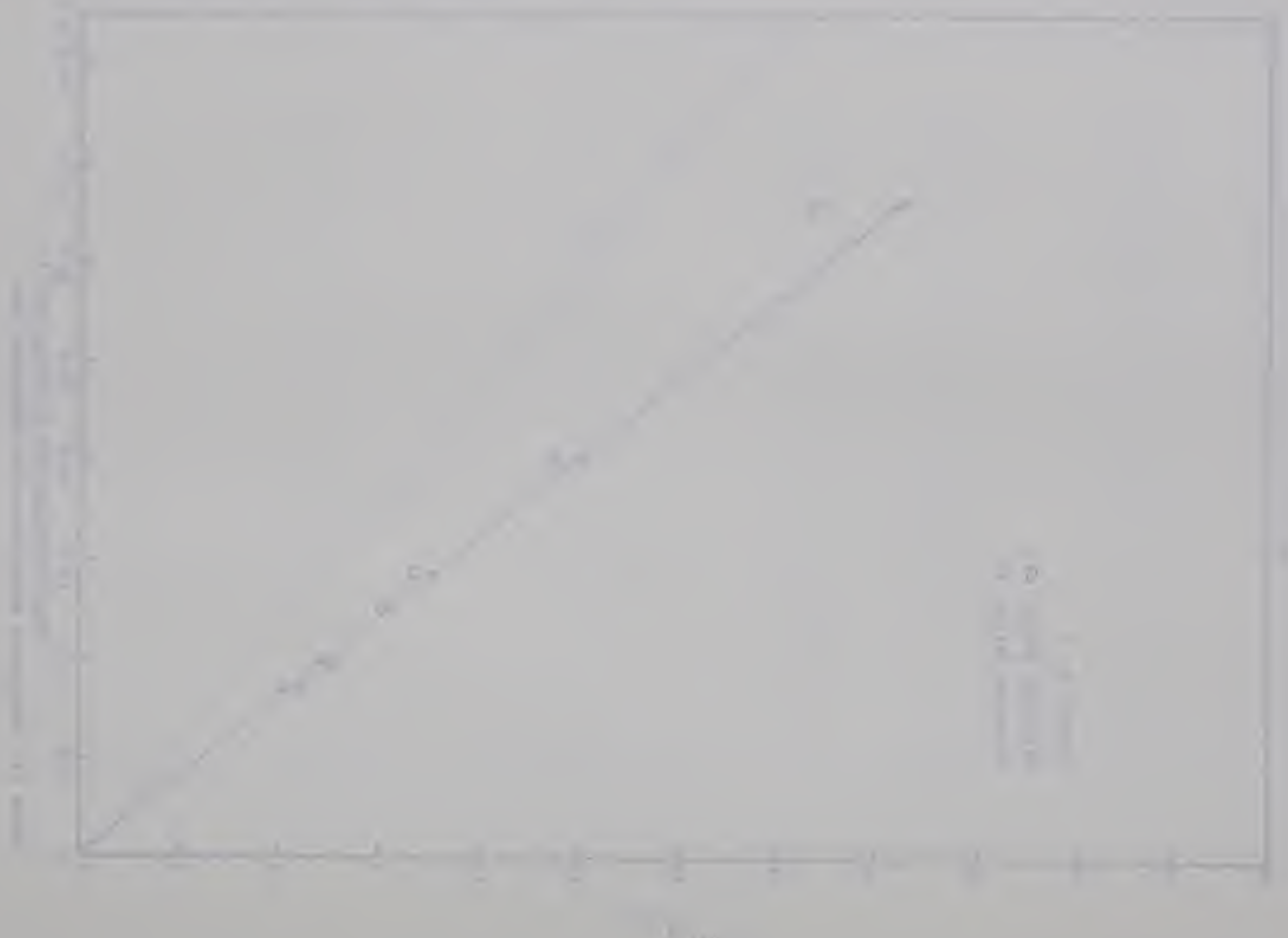


Figure 11: Reciprocal Rating Curve for Hacksawing Task.



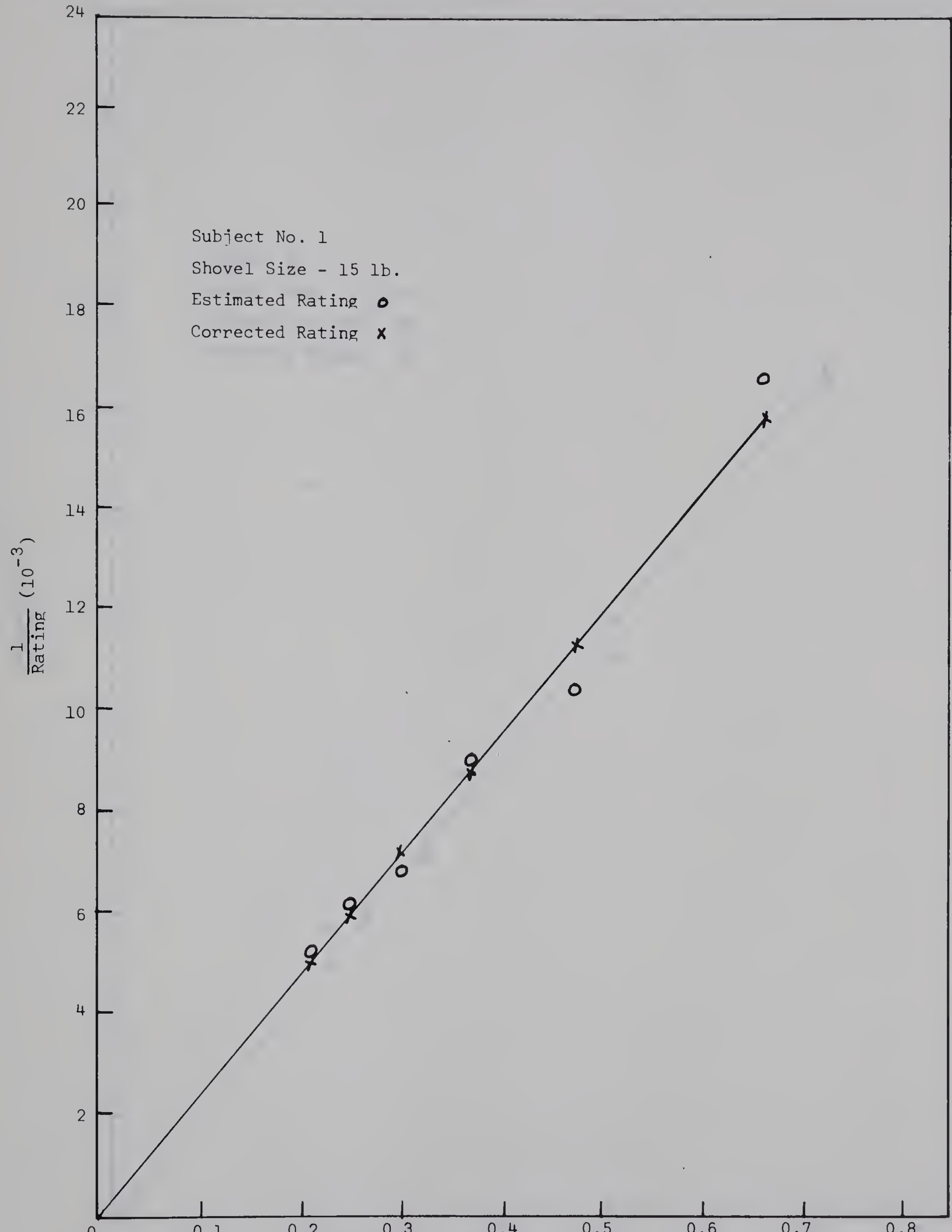


Figure 12: Reciprocal Rating Curve for Shovelling Task.

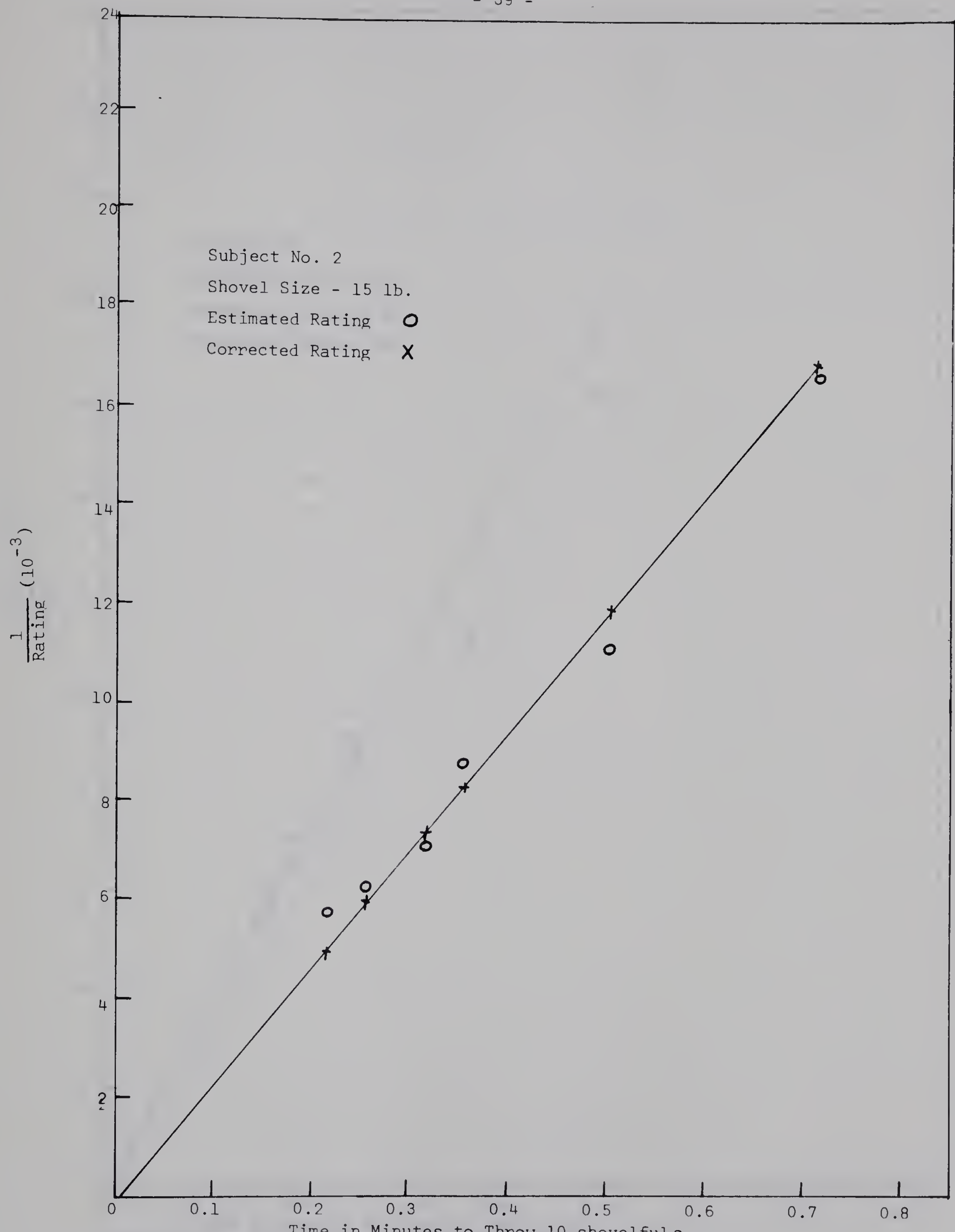


Figure 13: Reciprocal Rating Curve for Shovelling Task.

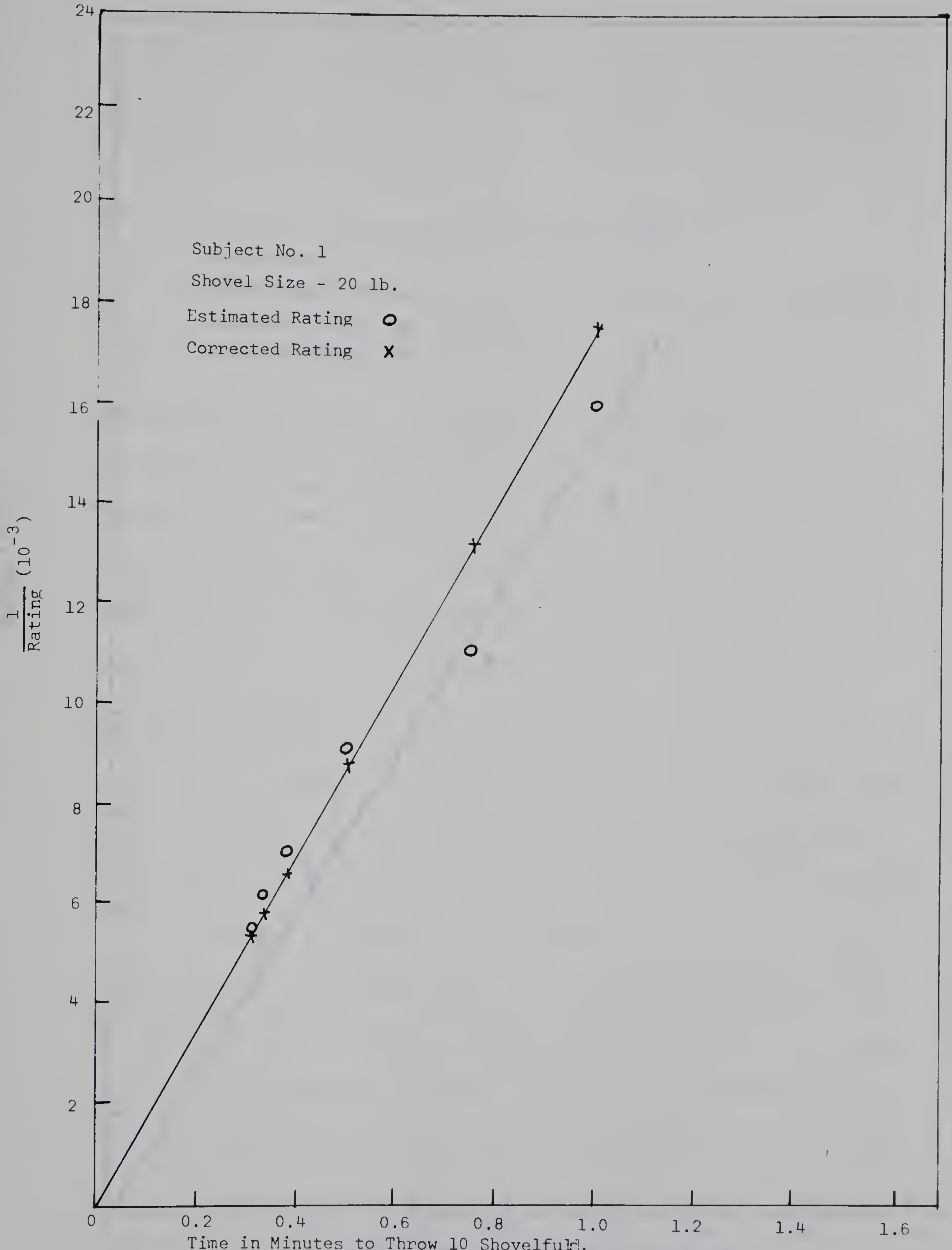


Figure 14: Reciprocal Rating Curve for Shovelling task.

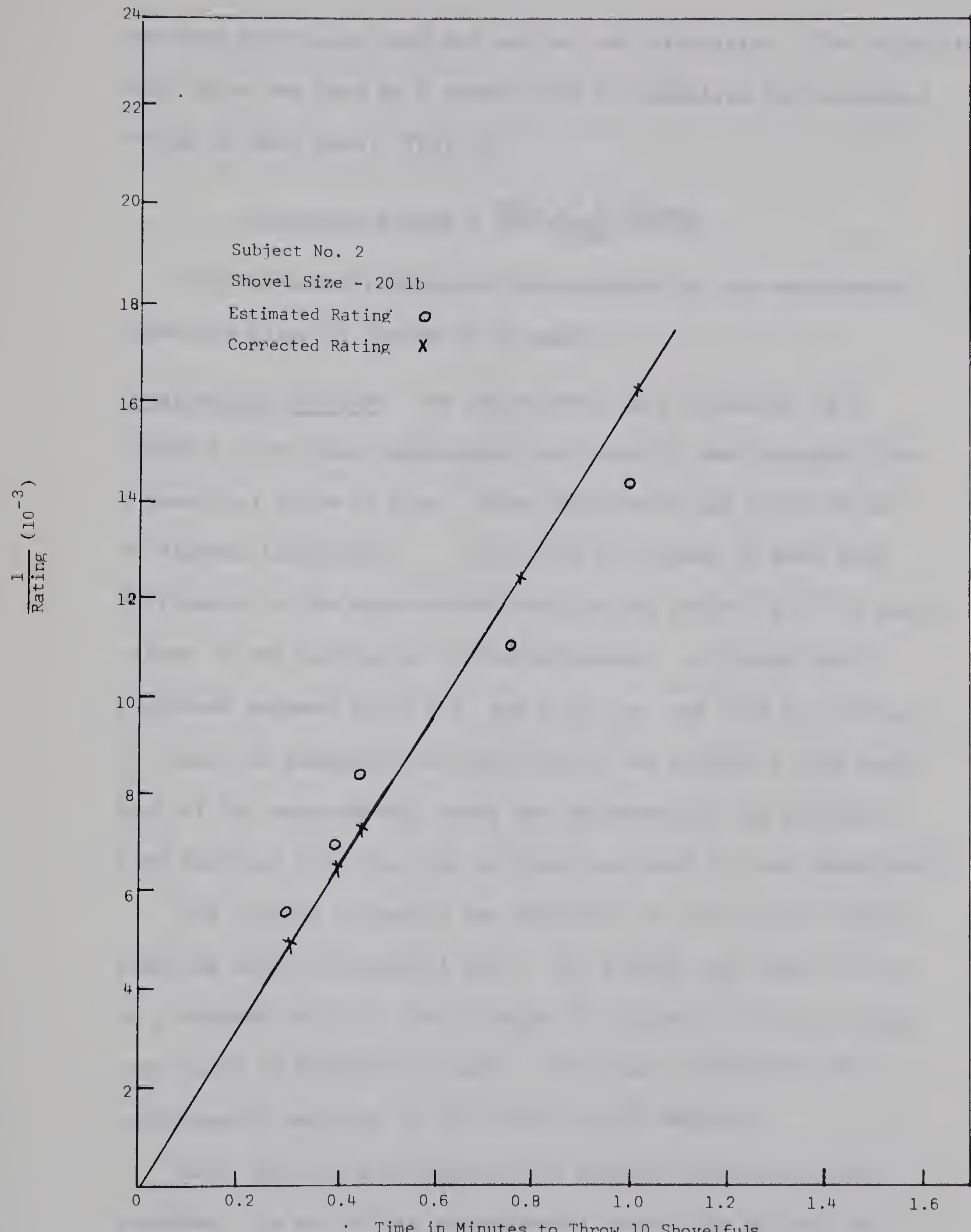
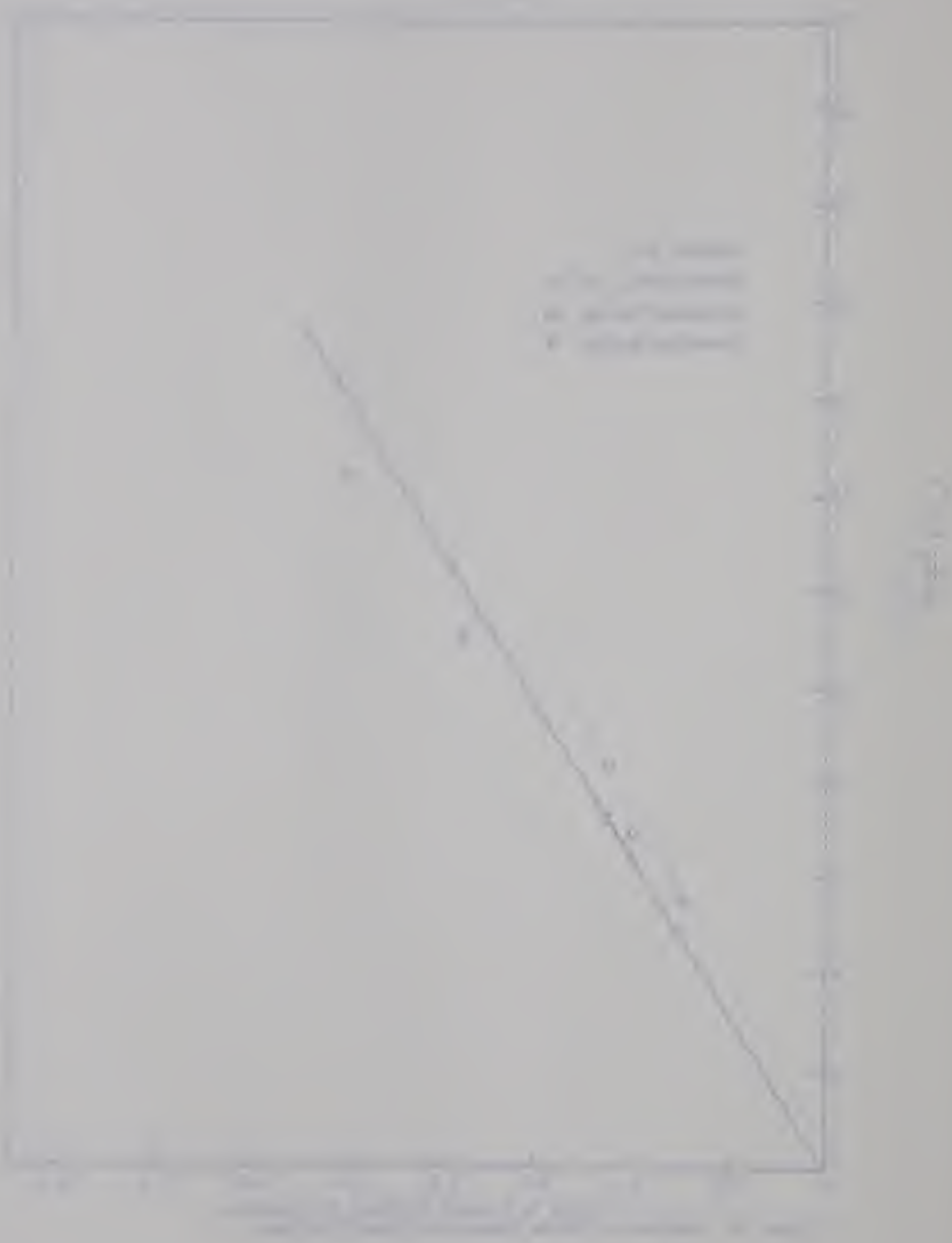


Figure 15: Reciprocal Rating Curves for Shovelling Task.



for that particular task and subject was calculated. The calculated mean value was used as a coefficient to calculate the corrected rating in each case. That is,

$$\text{Corrected Rating} = \frac{\text{Mean of K Values}}{\text{Time}}$$

The corrected ratings of the subjects for the experimental tasks are given in Tables 2, 3, and 4.

Experimental Routine: The experiments were conducted in a research room where temperature and humidity were constant from a practical point of view. Room temperature was about 65 to 70 degrees Fahrenheit. As it did not appear to make much difference to the experimental results,the subject did the tasks either in the morning or in the afternoon. All tasks were performed between 10:00 a.m. and 1:00 p.m. and 2:00 to 5:00 p.m. to insure an adequate time lapse since the subject's last meal. Each of the experimental tasks was performed by two subjects, both familiar with the type of tasks employed in this experiment.

The testing procedure was explained to the subject before starting each experimental task. The subject was asked to sit in a relaxed position for at least 10 minutes so that his pulse rate might be measured at rest. Pulse rate thereafter was continuously recorded on the ultra-violet recorder.

Each task was performed by the subject standing on the platform. In all of the experimental tasks, the subject was asked to work for at least six different ratings or paces varying between less than the normal to the maximum pace the subject could attain. Maximum pace meant that at which the

subject was exhausted after the elapsed time. Heart rate and forces developed while performing a task were recorded during the working period for each rate of work. In the first hacksawing test, each subject was asked to perform the job at a speed which he thought was normal. However, the subjects were provided with an indication and description of the system to allow them to decide their own approximate normal speed. The subjects were required to cut the square iron bar fastened in the vice on the work bench mounted on the platform. An iron bar of small cross-section was selected as this provided an accurate measure of the output at the end of each test. The subject was instructed to keep the pace of working constant throughout the timed working period. Four minute intervals were selected to obtain the subject's heart rate and forces developed during each test. During each testing session, each subject was rated and timed for a fixed number of work cycles. After working at one pace, the subjects were instructed to sit in a relaxed position until their heart rates were restored to rest heart rate and then the next testing session was continued.

In the shovelling task, each of the two different sizes of shovels were tried. With each shovel size, six different paces of shovelling were selected. The paces of shovelling varied from less than the normal to the highest the subject could reach and which resulted in physical exhaustion. In this task the working period was also four minutes, during which heart rate and forces were recorded. Each of the testing sessions was followed by a resting period to restore the subject's heart rate to his

normal at rest heart rate.

METHOD OF ANALYSIS

Quantification of Force Traces: The force platform measured the force developed due to bodily movements of subjects with respect to time. Due to several variables encountered during the tasks and the different bodily movement, force does not remain constant with respect to time. Therefore it became necessary to find a method for quantifying the force traces obtained for different jobs and for different subjects. Greene (16) used two methods for the quantification of such traces (a) the area under time curve and (b) sum of the peak forces. Both techniques of quantification were found to have a pooled linear correlation as high as 0.987, as was found by Barany (4). In other words, 97.4 percent of the variation in the area under the force traces could be explained by the linear regression of this factor on the sum of peak forces index. However, in the present investigation, the areas under the curves were obtained by integrating the force traces and the base line corresponding to zero activity level.

A second major part of the quantification was to evaluate the relative weights of three orthogonal components of given force. A visual comparison of force traces shown in Figure 16 obtained for the hacksawing task indicates clearly that the vertical and lateral force components are very small in

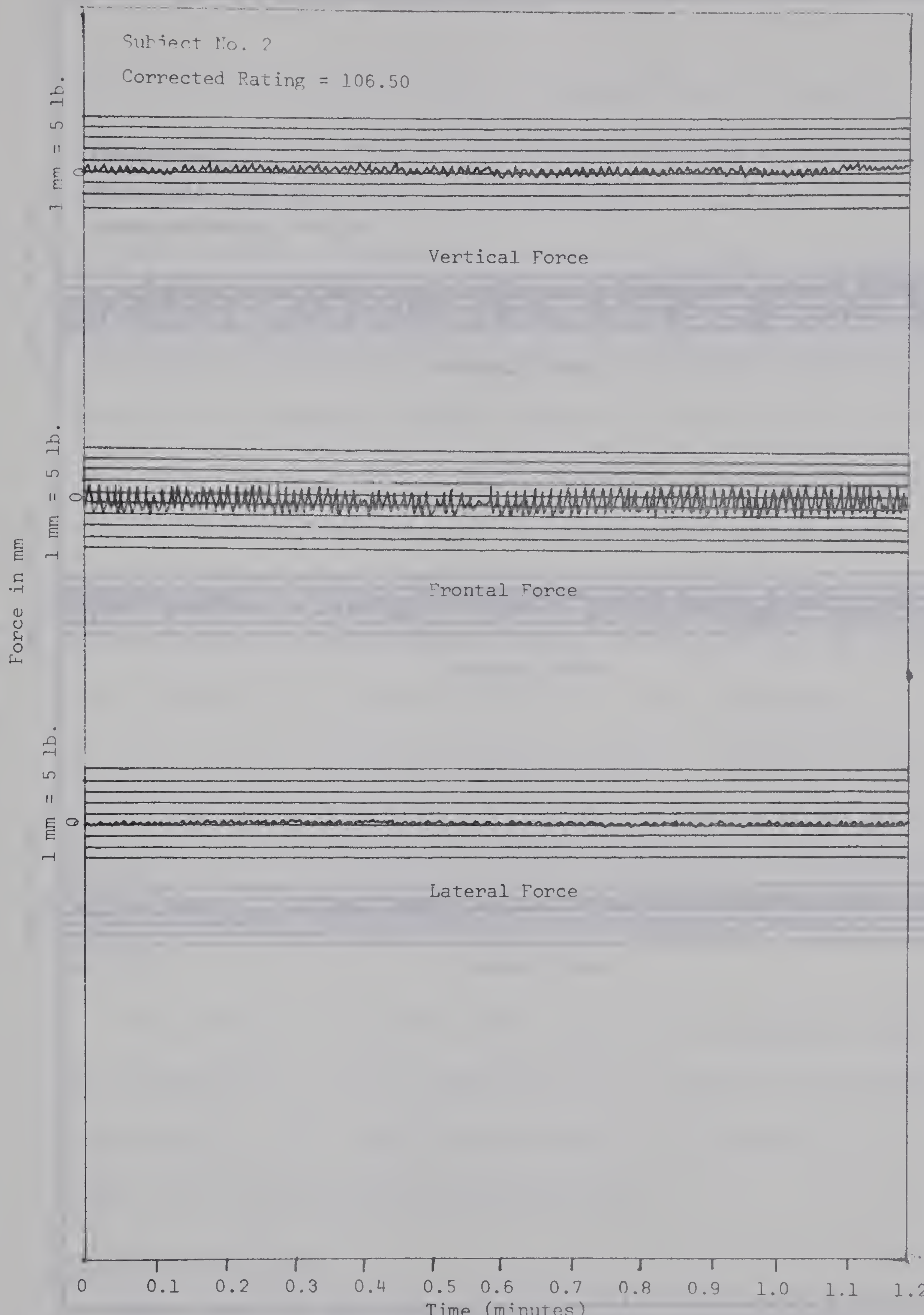


Figure 16: Force Traces of One Subject for Hacksawing Task.

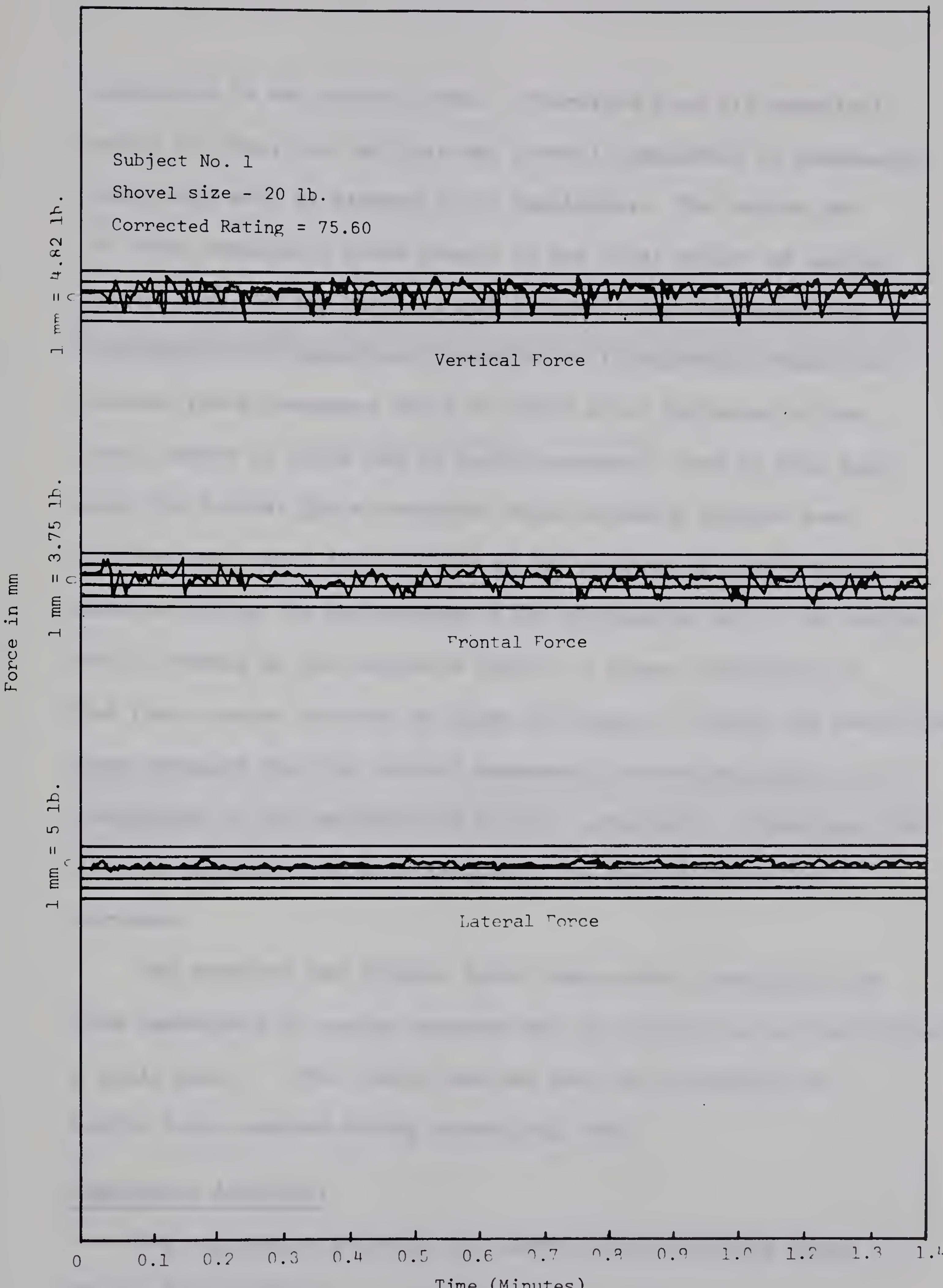


Figure 17: Force Traces of One Subject for Shovelling Task.

comparison to the frontal force. Therefore from all practical points of view, the vertical and lateral components in hacksawing could very well be assumed to be negligible. The vector sum of force components would result in the total amount of exerted force. But, if the vertical and lateral force components are considered to be practically negligible in magnitude, then the frontal force component could be taken as an indicator of the total amount of force due to bodily movement. Due to this fact, only the frontal force component which showed a uniform wave pattern was taken into account as the measure of bodily forces exerted during the performance of the hacksawing task. The vector sum is termed as the composite force. A visual comparison of the force traces obtained as shown in Figure 17 during the shovelling task revealed that the lateral component is very small in comparison to the vertical and frontal components. Therefore, the lateral component could be assumed to be zero for practical purposes.

The vertical and frontal force traces were integrated over time seperately by analog computer and the vector sum was calculated with a slide rule. This vector sum was used as the measure of bodily force exerted during shovelling task.

Regression Analysis:

The regression analysis was based on the following model for true population:

$$Y = A + BX$$

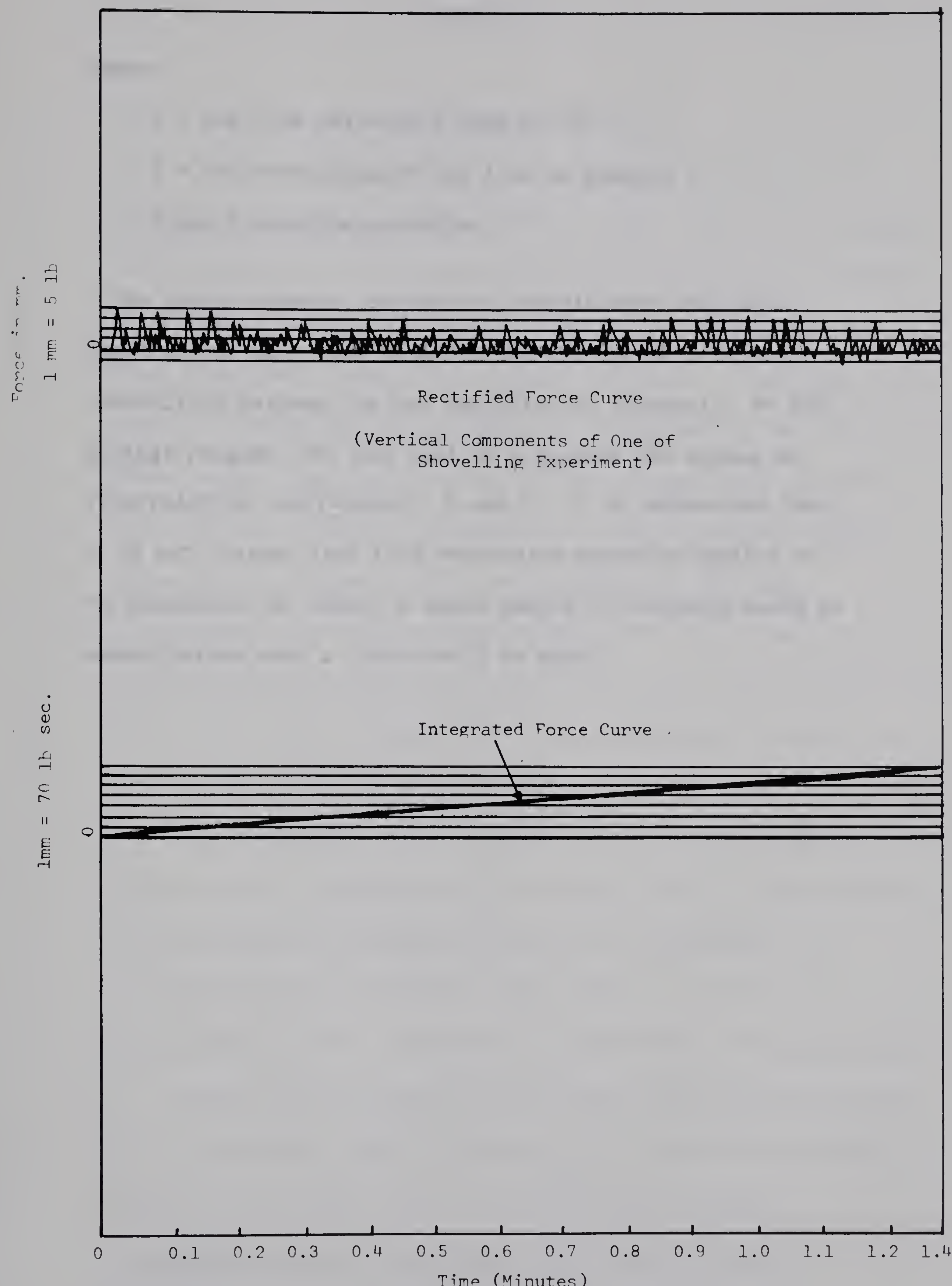


Figure 18: Sample Integrated Force Curve.

where

A = the true value of Y when X = 0

B = the true slope of the line to predict Y

X and Y were the variables.

The product-moment correlation coefficients (36) were computed for each task to determine the degree of linear correlation between the two variables of interest. An APL package program (35) was used to calculate the values of r(correlation coefficient), A and B. It is emphasized that it is not claimed that this regression equation applies to the population at large, a large sample of subjects would be needed before wuch a claim could be made.

CHAPTER IV

1. RESULTS AND DISCUSSION

<u>Heart Rate Measurement</u>: The subjects'heart rates were recorded as an indicator of the physiological load under actual working conditions for each experimental task. The heart rates have been determined during 3 to 4 minute intervals. This heart rate could be considered as approximately "the steady state of heart rate". Steady state heart rate refers to the constant level of heart rate that will persist throughout the longer working periods. Shepard (34), Karpovich (20) and Astrand (2), in their investigation of step test and cycling ,have shown that ,at most working rates ,the heartrate during a 3-4 minute test is 85 to 95% of the steady state. Maximum heart rate change takes place during the first 1 1/2 minutes (20)

The transmitter unit to detect the heart beat, which was carried by the subject ,did not interfere with his normal working procedure while performing the task, thus exploiting the advantage of using telemetric heart rate as a measure of physiological load in comparison to measurement of oxygen intake.

Schertz (32) noticed the interfering effect of mouth pieces used in measuring oxygen consumption and claimed that measured energy is 18% higher than the actual energy required.

<u>Relationship Between Work Study Rating and Heart Rate</u>:

Work study rating assessments are given in Tables 5, 6 and 7 for hacksawing and grain shovelling tasks, together

TABLE 5.

CORRECTED RATINGS, HEART RATES, COMPOSITE FORCE AND AVERAGE FORCE FOR HACKSAWING TASK.

	Test No.	Corrected Rating	Working Heart Rate(Beats/Min)	Increase in Heart Beat Above Rest Level	Composite Force in lb-sec/min.	Average Force in lb.
Subject No. 1 (Rest Heart Rate =89)						
	1	69.00	108	19	263.00	4.383
	2	83.90	115	26	290.00	4.830
	3	90.40	131	42	394.50	6.570
	4	117.30	145	56	530.00	8.830
	5	147.00	166	77	700.00	11.660
	6	168.00	176	87	817.00	13.610
Subject No. 2 (Rest Heart Rate =72)						
	1	40.70	82	10	90.00	1.500
	2	67.20	100	28	230.00	3.830
	3	96.00	107	35	300.00	5.000
	4	103.30	123	51	430.00	7.160
	5	149.30	132	60	550.00	9.160
	6	168.00	142	70	680.00	11.330

TABLE 6 .

CORRECTED RATINGS, HEART RATES, COMPOSITE FORCE AND AVERAGE FORCE FOR SHOVELLING TASK .
(Shovel Size - 15 lb)

	Test No.	Corrected Rating	Working Heart Rate(Beats/Min)	Increase in Heart Beat Above Rest Level	Composite Force in lb-sec/min.	Average Force in lb.
Subject No. 1 (Rest Heart Rate =87)						
	1	62.50	110	23	262.50	4.70
	2	88.00	118	31	363.75	6.62
	3	112.00	127	40	465.00	7.75
	4	138.00	140	53	610.00	10.16
	5	166.00	154	67	770.75	12.84
	6	197.00	172	85	910.00	15.16
Subject No. 2 (Rest Heart Rate =74)						
	1	59.50	95	21	235.00	3.91
	2	84.50	101	27	342.50	5.71
	3	105.80	108	34	455.25	7.59
	4	136.20	120	46	606.33	10.10
	5	169.00	138	64	745.00	12.41
	6	201.00	148	74	861.00	14.35

TABLE 7

CORRECTED RATINGS, HEART RATES, COMPOSITE FORCE AND AVERAGE FORCE FOR SHOVELLING TASK
(Shovel Size - 20 lb)

	Test No.	Corrected Rating	Working Heart Rate(Beats/Min)	Increase in Heart Beat Above Rest Level	Composite Force in lb-sec/min.	Average Force in lb.
Subject No. 1 (Rest Heart Rate =88)						
	1	56.20	106	18	236.00	3.93
	2	79.00	110	22	330.50	5.51
	3	113.00	120	32	473.00	7.88
	4	148.00	139	51	618.75	10.31
	5	170.20	158	70	725.00	12.83
	6	181.20	170	82	850.00	14.17
Subject No. 2 (Rest Heart Rate =72)						
	1	61.06	88	16	221.00	3.68
	2	79.40	92	20	281.75	4.69
	3	135.80	113	41	473.00	7.88
	4	152.50	118	46	528.75	8.81
	5	200.56	143	71	820.00	13.66

with the working heart rate for the two subjects. Rating and working heart rate in beats per minute were plotted in order to detect the presence, if any, of relationships between working heart rate and performance rating. A close relationship existed and a linear model appeared to describe the relationship between the two variables. Therefore straight lines were fitted through the observations of heart rate and rating by the method of least squares. These plots are shown in Figures 19, 20, 21 and 22. The numerical values of intercepts, slopes, and correlation coefficients are tabulated in Table 8.

In view of these correlation coefficients it is evident that the two variables, the pulse rate and the rating are closely correlated over the full range of heart rate values, which varies with physical effort from a low pace to a high pace. A further examination of Table 8 also reveals that the regression coefficients and intercept are different for the two subjects within the same task and for different tasks. Subject No. 1 has consistently higher values of heart rate than subject No. 2 in all experiments. If it is assumed that the intensity of work is proportional to increase in pulse rate (28) above the rest level, then a similar straight line model should describe the relation between these two variables as was the case when working heart rates were plotted. Further, it was assumed that increase in heart rate was a function of the intensity of work and job difficulty or type of job. In order to examine the proportionality relationship, independent

TABLE 8.

LINEAR REGRESSION ANALYSIS OF RATING ON WORKING HEART RATE.

Task	Subject No.	Regression Coefficient	Regression Constant	Correlation Coefficient
Hacksawing				
	1	o.75	56.89	0.99
	2	0.49	64.39	0.98
Shovelling (shovel size - 15 lb)				
	1	0.49	77.58	0.99
	2	0.39	68.68	0.99
(shovel size - 20 lb)				
	1	0.49	72.08	0.96
	2	0.39	61.13	0.99

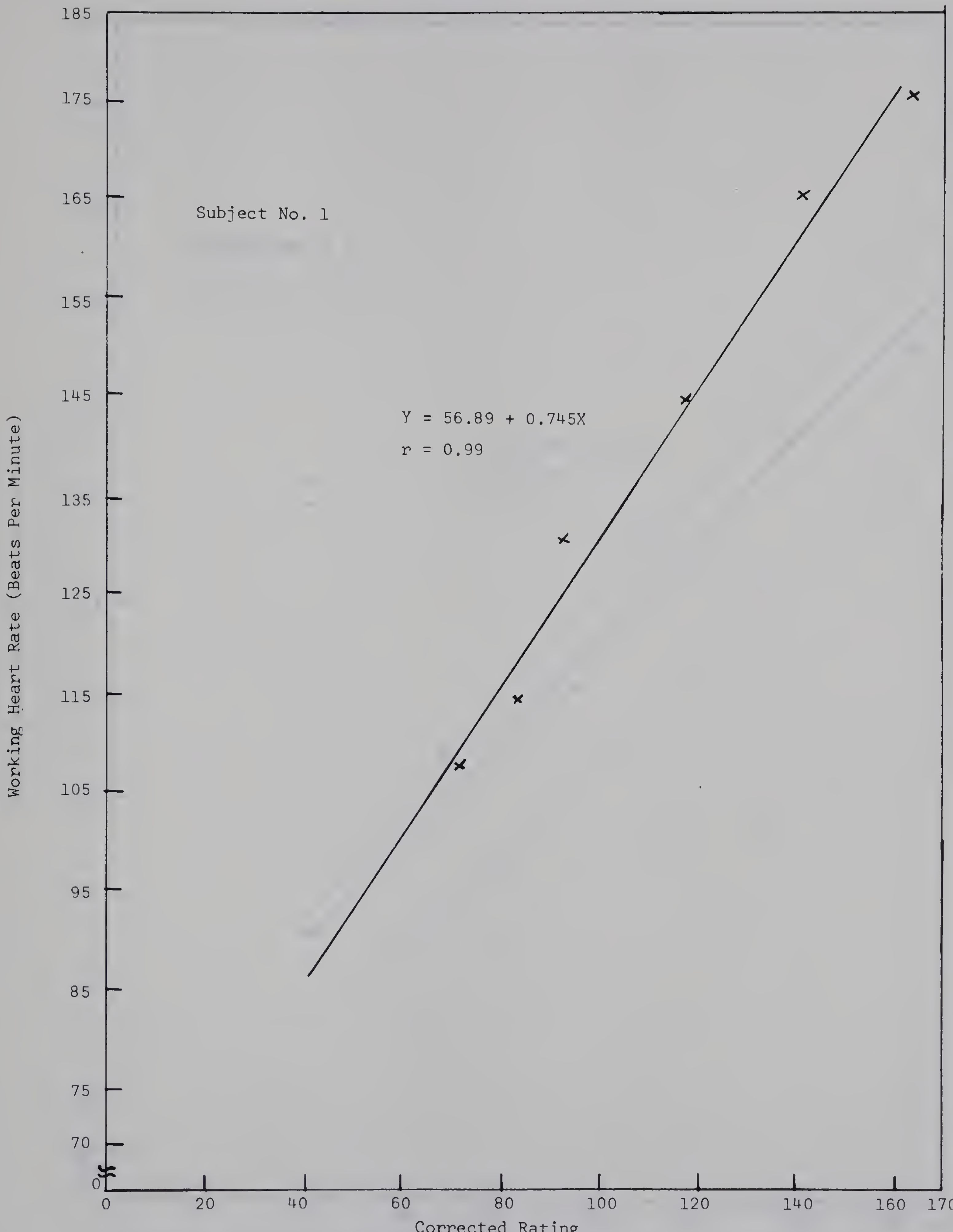


Figure 19: Regression of corrected rating on working heart rate for hacksawing task.

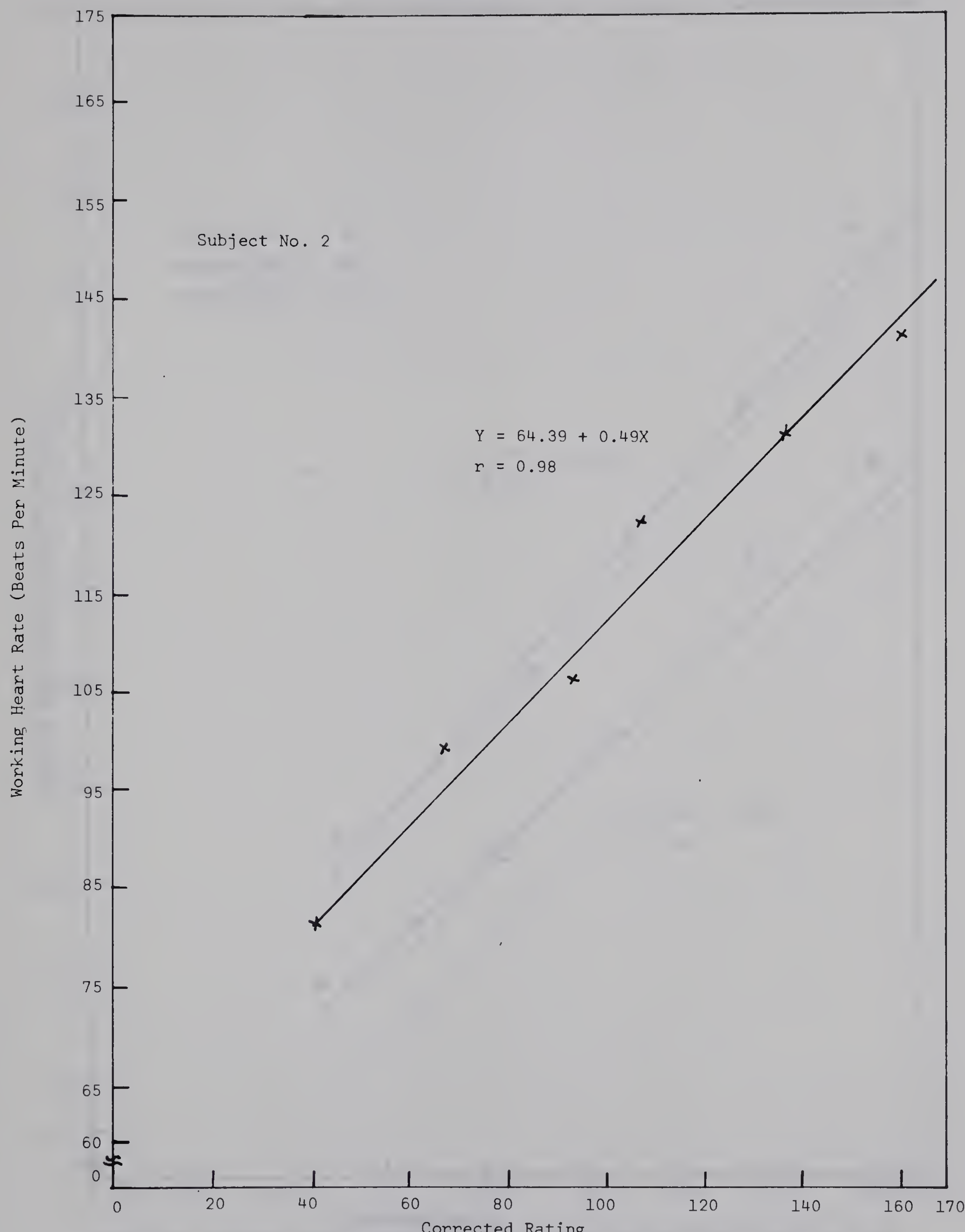


Figure 20: Regression of corrected rating on working heart rate for hacksawing task.

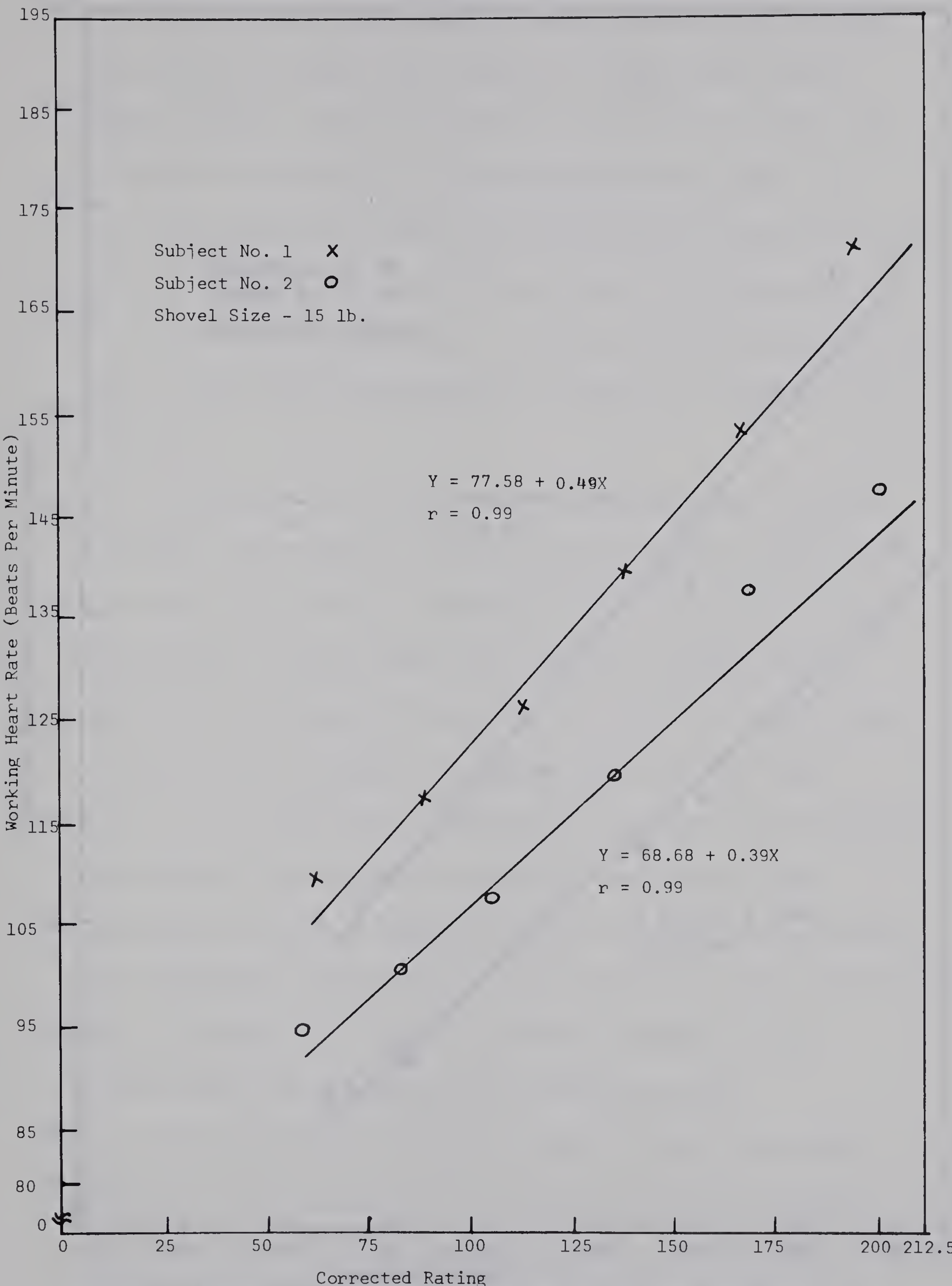
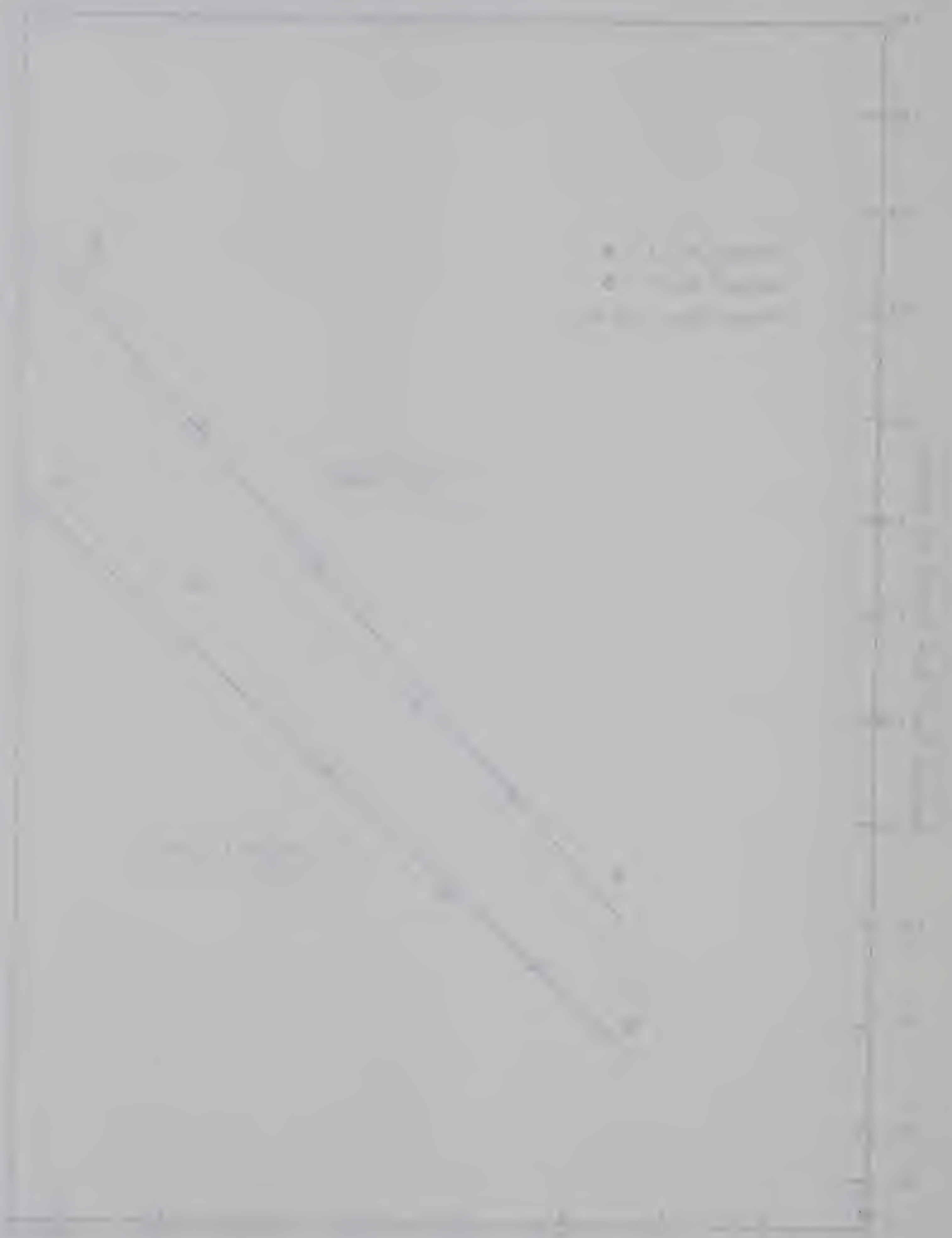


Figure 21: Regression of corrected rating on working heart for shovelling task.



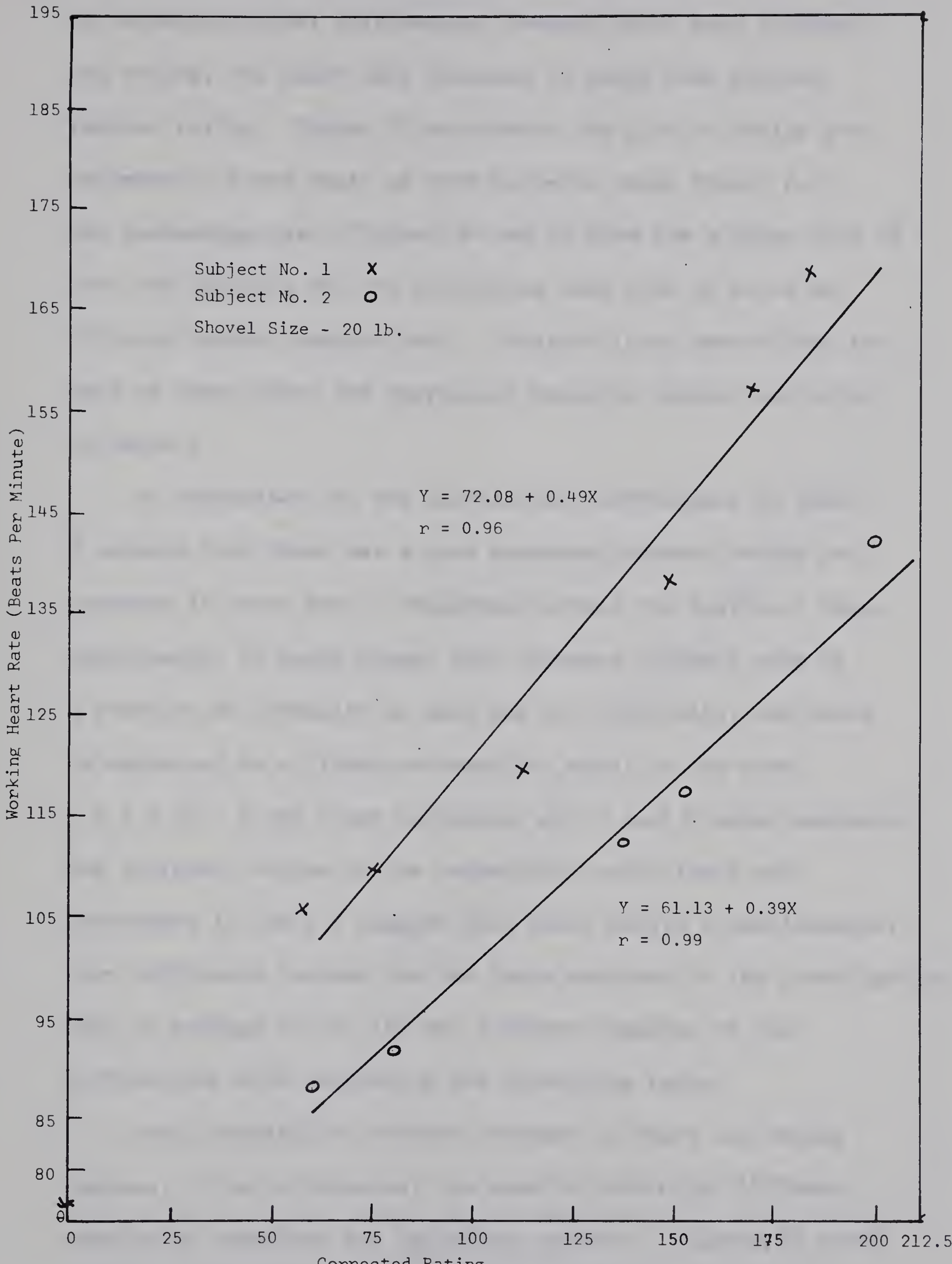


Figure 22: Regression of corrected rating on working heart rate for shovelling task.

of intra-individual differences, between heart rate increase and rating, the heart rate increase in beats were plotted against rating. Figure 23 represents the plot of rating and increase in heart beats of both subjects under study for the hacksawing task. Figures 24 and 25 show the similar plot of both the subjects for the shovelling task with 15 pound and 20 pound shovels respectively. Straight lines were fitted for each of these plots and regression analysis results are given in Table 9.

An examination of the correlation coefficients in Table 9 reveals that there was a good agreement between rating and increase in heart rate. Therefore, within the limits of these experiments, it would appear that increase in heart rate is a function of intensity of work and job difficulty, and could be expressed by a linear mathematical model of the form $Y = A + BX$. X and Y are variables with A and B being constants. The different values of the regression coefficients and intercepts in Table 9 suggest that there exists a physiological cost difference between the two tasks employed in the investigation. This is perhaps due to the two different degrees of job difficulties with hacksawing and shovelling tasks.

Good correlations between increase in heart and rating reduces, if not eliminates, the need for obtaining different prediction equations for individual workers. However, to prove this result further research is required with a greater number of subjects.

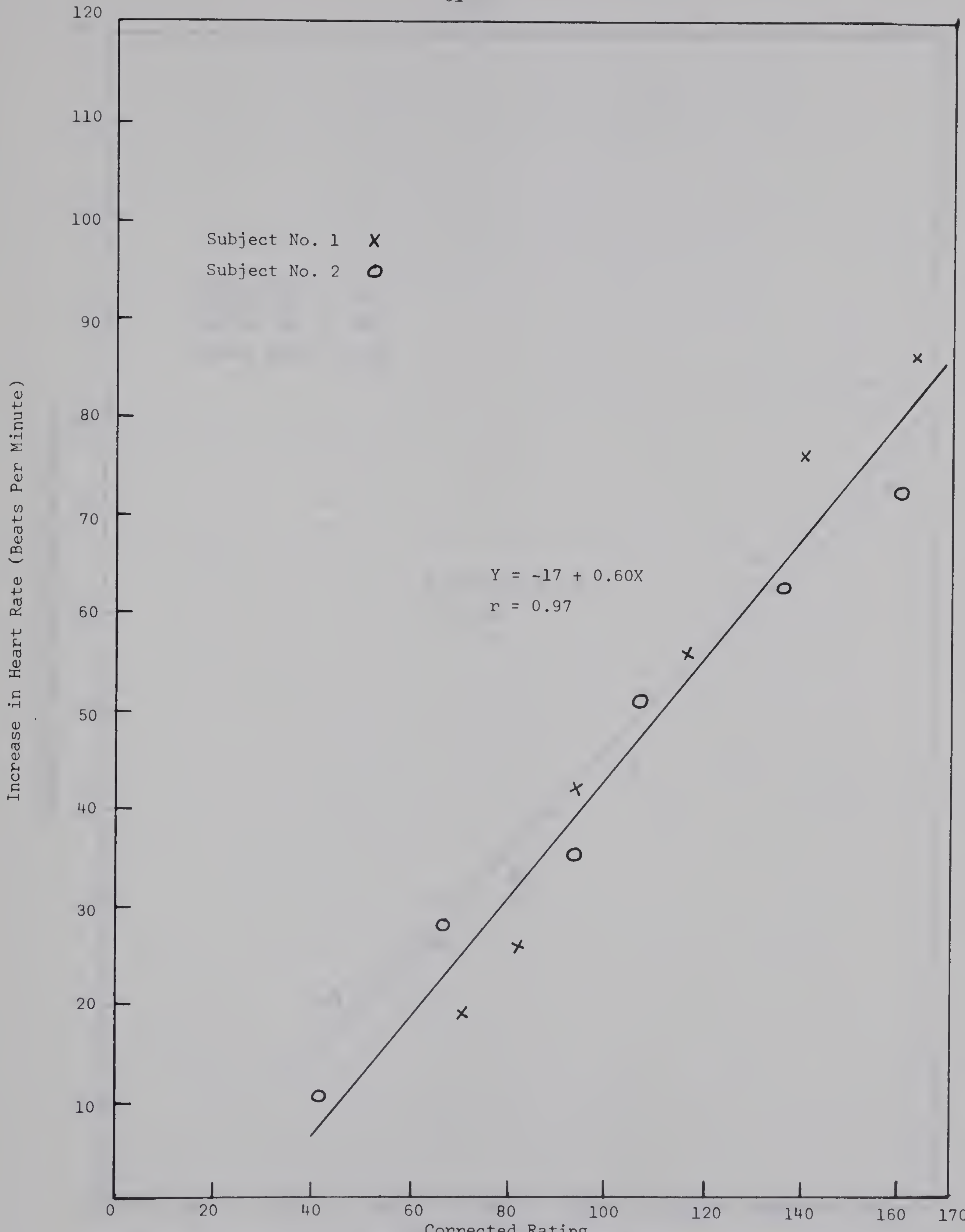


Figure 23: Regression of corrected rating on increase in heart rate for hacksawing task.

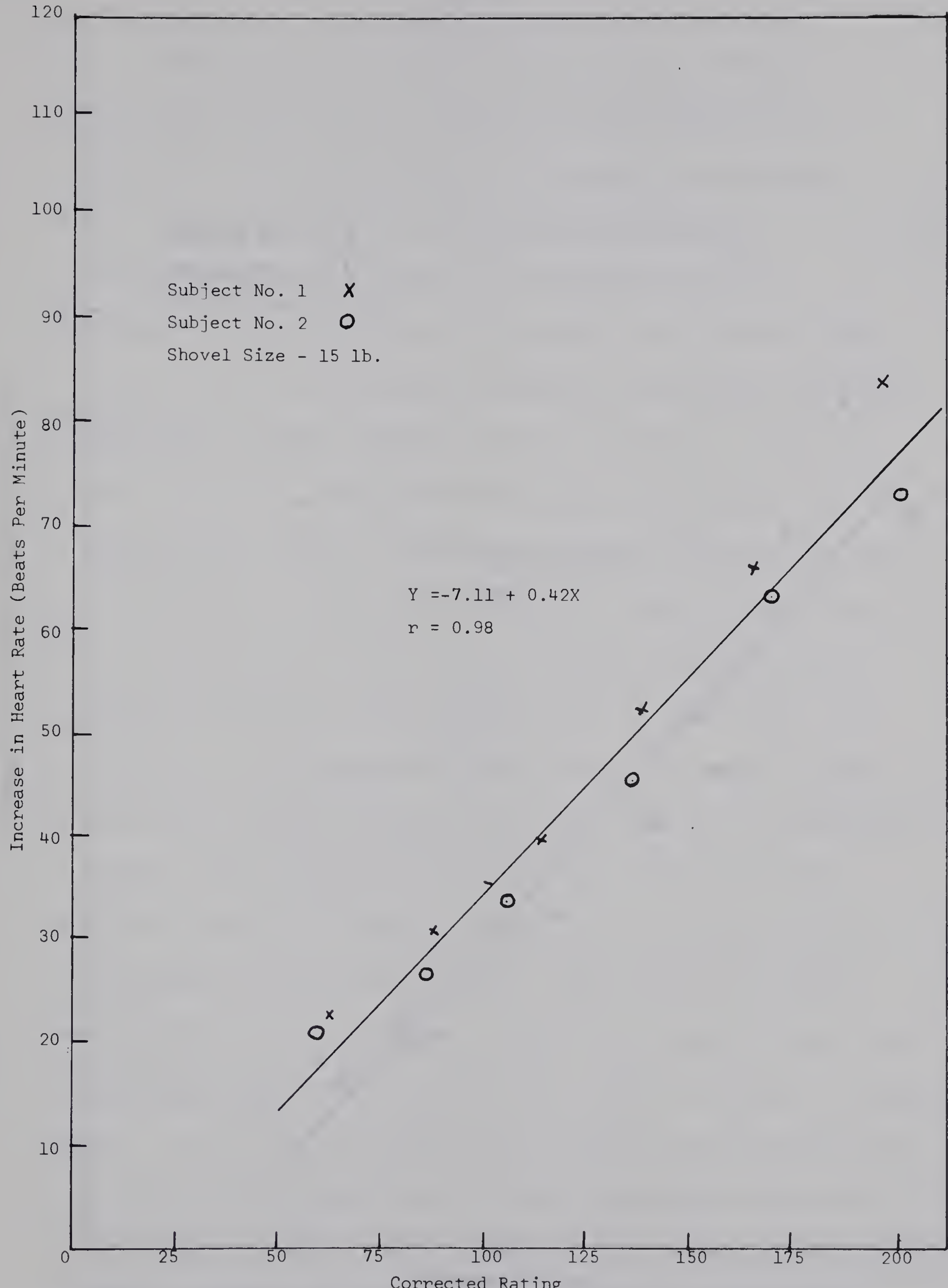


Figure 24 : Regression of corrected rating on increase in heart rate for shovelling task.

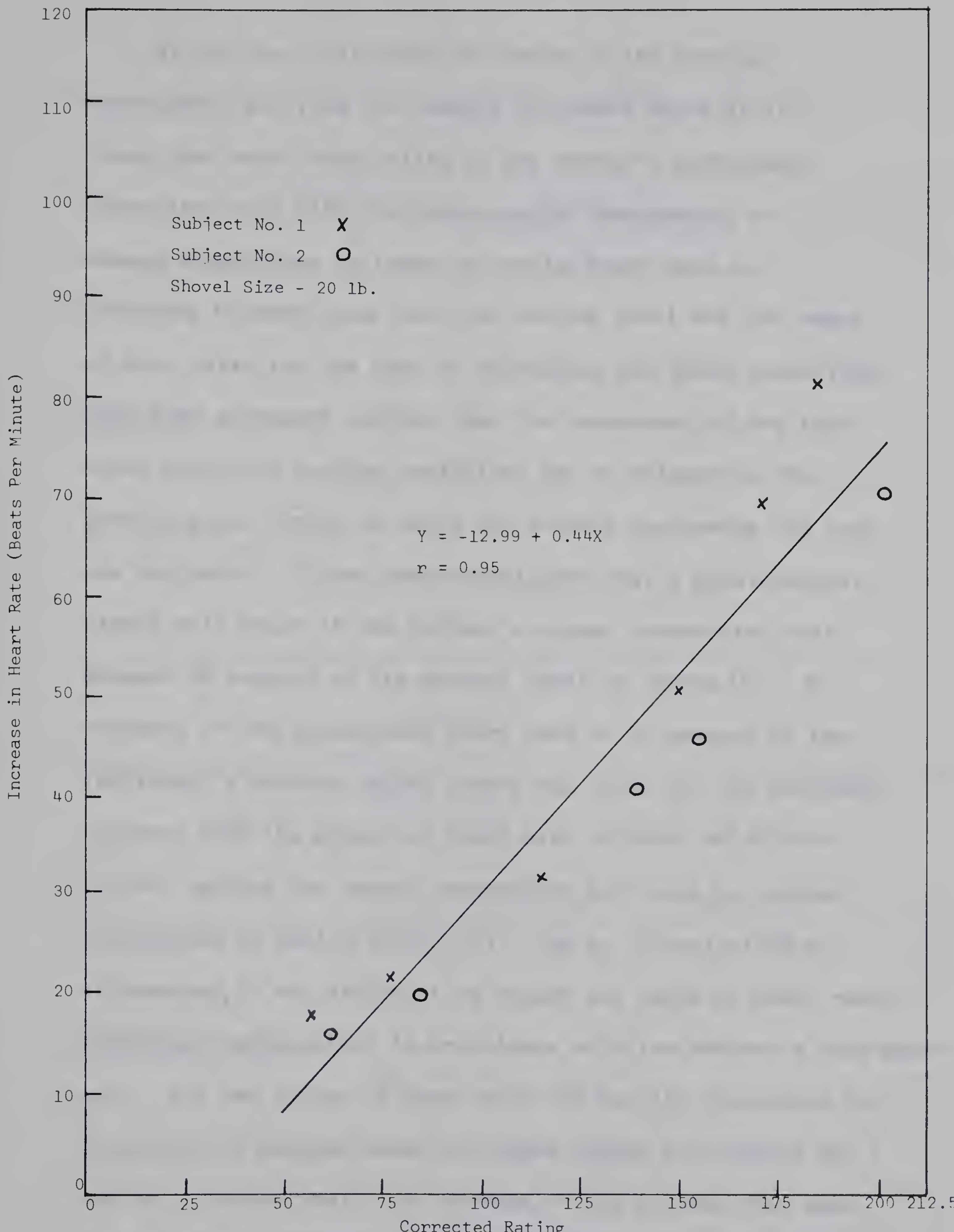


Figure 25: Regression of corrected rating on increase in heart rate for shovelling task.

Within the limitations of design of the working experiments and from the results discussed above ,it is clear that work study rating of the worker's performance correlates well with the physiological measurement of energy expenditure in terms of working heart rate or increase in heart rate over the resting level and the range of work rates for the task of hacksawing and grain shovelling. This good agreement implies that the assessment of the task under practical working conditions can be related to the physiological strain to which the workers performing the task are subjected. It has been established that a physiological strain will occur if the subject's oxygen consumption rate exceeds 50 percent of his maximal level of intake (2). An estimate of the approximate heart rate at 50 percent of the individual's maximum oxygen intake was found for the available subjects from the graphs of heart rate in beats per minute plotted against the oxygen consumption in litres per minute illustrated by Maritz, et al (25). Due to intra-individual differences, it was difficult to select one value of heart rate. However,by manipulation in accordance with the subject's rest heart rate , the two values of heart rate 130 and 110 correspond to 50 percent of maximum level of oxygen uptake for subject No. 1 and No. 2 respectively. On average, it was assumed that mean oxygen intake was about 3 liters per minute. Corresponding to these heart rates for the individual subject, ratings were calculated from the prediction equations and are tabulated in Table 10.

TABLE 9 .

LINEAR REGRESSION ANALYSIS OF RATING ON INCREASE IN HEART RATE .

Task	Subject No.	Regression Coefficient	Regression Constant	Correlation Coefficient
Hacksawing				
	1 & 2	0.60	-17.00	0.97
Shovelling (shovel size - 15 lb)				
	1 & 2	0.42	- 7.11	0.98
(shovel size - 20 lb)				
	1 & 2	0.44	-12.99	0.95

TABLE 10 .

RATINGS CORRESPONDING TO HEART RATE OF 130 AND 110 BEATS PER MINUTE FOR SUBJECT NO. 1 AND SUBJECT NO. 2 RESPECTIVELY .

Task	Prediction Equation	Subject No.	Rating
Hacksawing	$\Delta H^{**} = -17 + 0.60R^{*}$	1	96.66
		2	85.16
Shovelling (shovel size - 15 lb)	$\Delta H = -7.11 + 0.42R$	1	119.30
		2	102.40
(shovel size - 20 lb)	$\Delta H = -12.99 + 0.44R$	1	130.81
		2	121.43

** ΔH = Increment in heart rate over the resting level.

* R = Rating.

It would thus appear that an average rating of 90 is the safe limit of worker's physical endurance for a hacksawing task. And on the average rating of 118 would be a safe limit for shovelling task. These ratings represent the normal working rate without any rest.

The rating factor of 90 and 118 may appear to contradict the normal rating factor of 100 as was defined earlier. This difference was probably caused by the subjective rating difficulties of assessment of effectiveness of the operator. However, it is important to note that, under adequate incentives, a worker is expected to work at a rating of 133. This performance rating would keep the worker under strain if he had no rest periods. Such over-strain above the normal will result in early fatigue. From this study, it would appear that such physiological studies could assist the work-study practitioner in assessment of relaxation allowances with an estimation of over-strain as might be predicted by the prediction equations given in Table 10. Further research is suggested to determine relationships between heart rate and rating factor for other practical tasks.

<u>Relationship Between Heart Rate And Force Time Curves</u>:

The original intention of the experiment was to relate heart rate to the reaction forces exerted by bodily movement as measured by the force platform. In this analysis, the resulting reaction forces are expressed as composite force in pound-second per minute and average force in pounds.

Composite force is equal to the vector sum of the vertical, frontal and lateral components of the integrated forces with respect to time. For the task of hacksawing, the composite force is equal to the frontal force alone, as the other two components were negligible. The composite force in the case of the shovelling task, only the vertical and frontal components were considered with respect to time. The average force is equal to the composite force divided by the time over which the force traces were integrated. The composite force and average force values are tabulated in Tables 5, 6 and 7 obtained for each of the subjects in the three experiments. Increase in heart rate above the resting level while performing their specified tasks is also included. Graphs were produced for each of the three experiments to correlate the heart rate increase with the composite force and with the average force. Composite forces were not related with working heart rate for an individual subject in order to reduce the number of prediction equations within a task. The graph of composite force versus increase in heart rate are shown in Figures 26, 27 and 28. The plots of average force against increase in heart rate are shown in Figures 29, 30 and 31. Straight lines were fitted for each of the three graphs and the product moment correlation coefficients were computed for each task to determine the degree of linear correlation between the two variables of interest. The results of regression analysis are tabulated in Tables 11 and 12. The regression lines are shown in Figures 26 to 31.

TABLE 11.

LINEAR REGRESSION ANALYSIS OF COMPOSITE FORCE ON INCREASE IN HEART RATE.

Task	Subject No.	Regression Coefficient	Regression Constant	Correlation Coefficient
Hacksawing				
	1 & 2	0.108	-0.89	0.98
Shovelling (shovel size - 15 lb)				
	1 & 2	0.091	-3.13	0.98
(shovel size - 20 lb)				
	1 & 2	0.100	-8.28	0.98

TABLE 12.

REGRESSION ANALYSIS OF AVERAGE FORCE ON INCREASE IN HEART RATE.

Task	Subject No.	Regression Coefficient	Regression Constant	Correlation Coefficient
Hacksawing				
	1 & 2	6.52	-0.885	0.98
Shovelling (shovel size - 15 lb)				
	1 & 2	5.56	-4.53	0.99
(shovel size - 20 lb)				
	1 & 2	5.91	-7.84	0.98

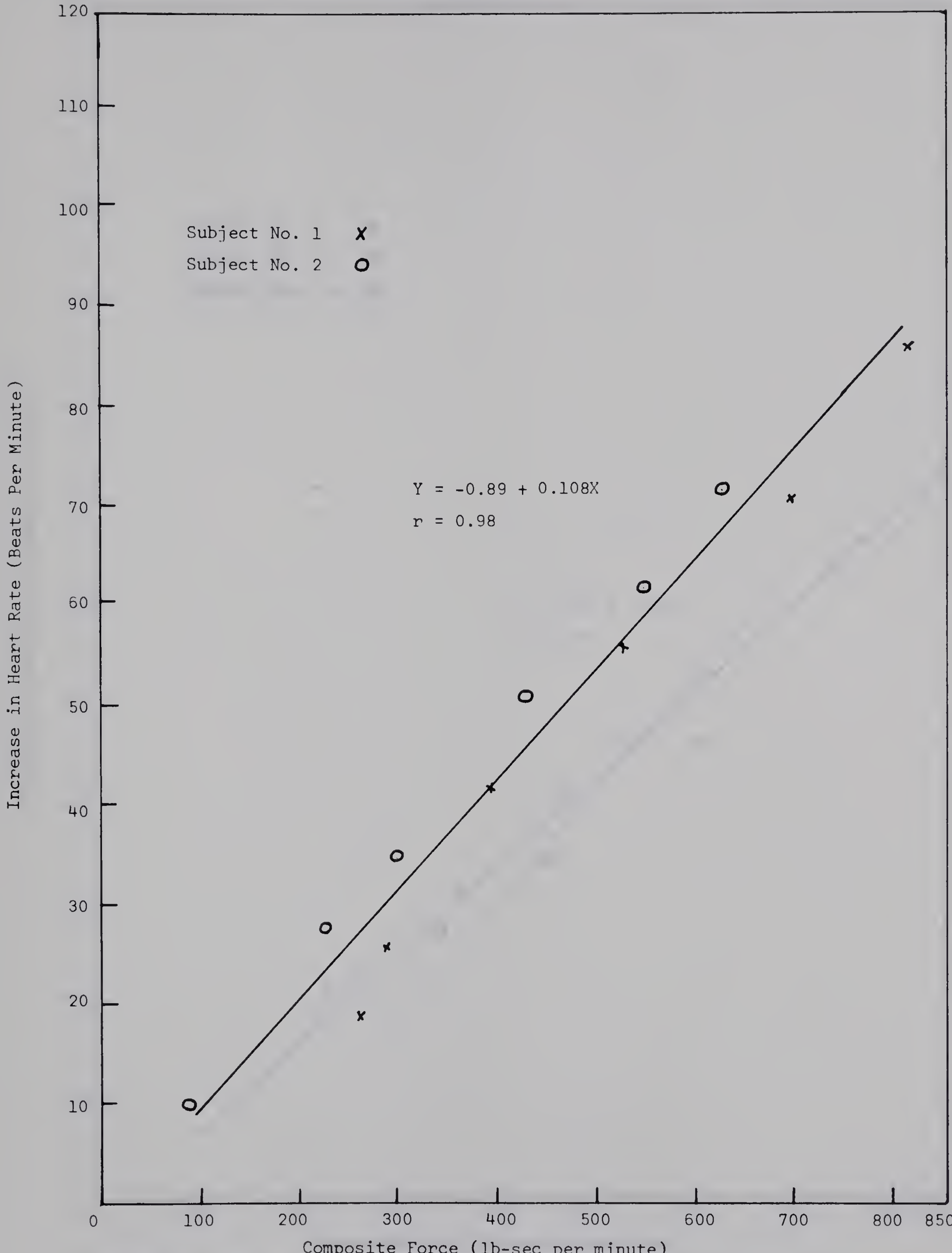


Figure 26: Regression of composite force on increase in heart rate for hacksawing task.

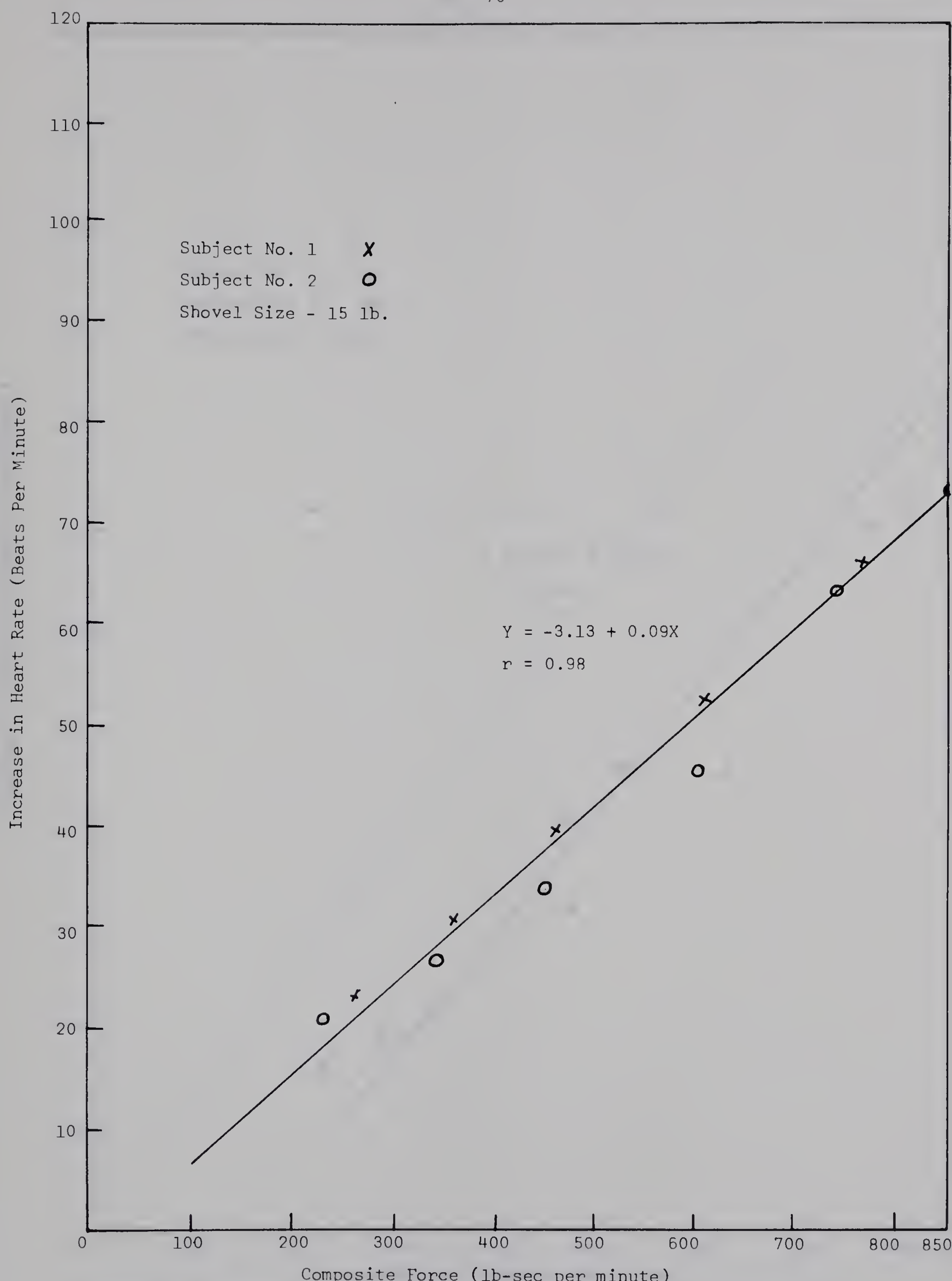


Figure 27: Regression of composite force on increase in heart rate for shovelling task.

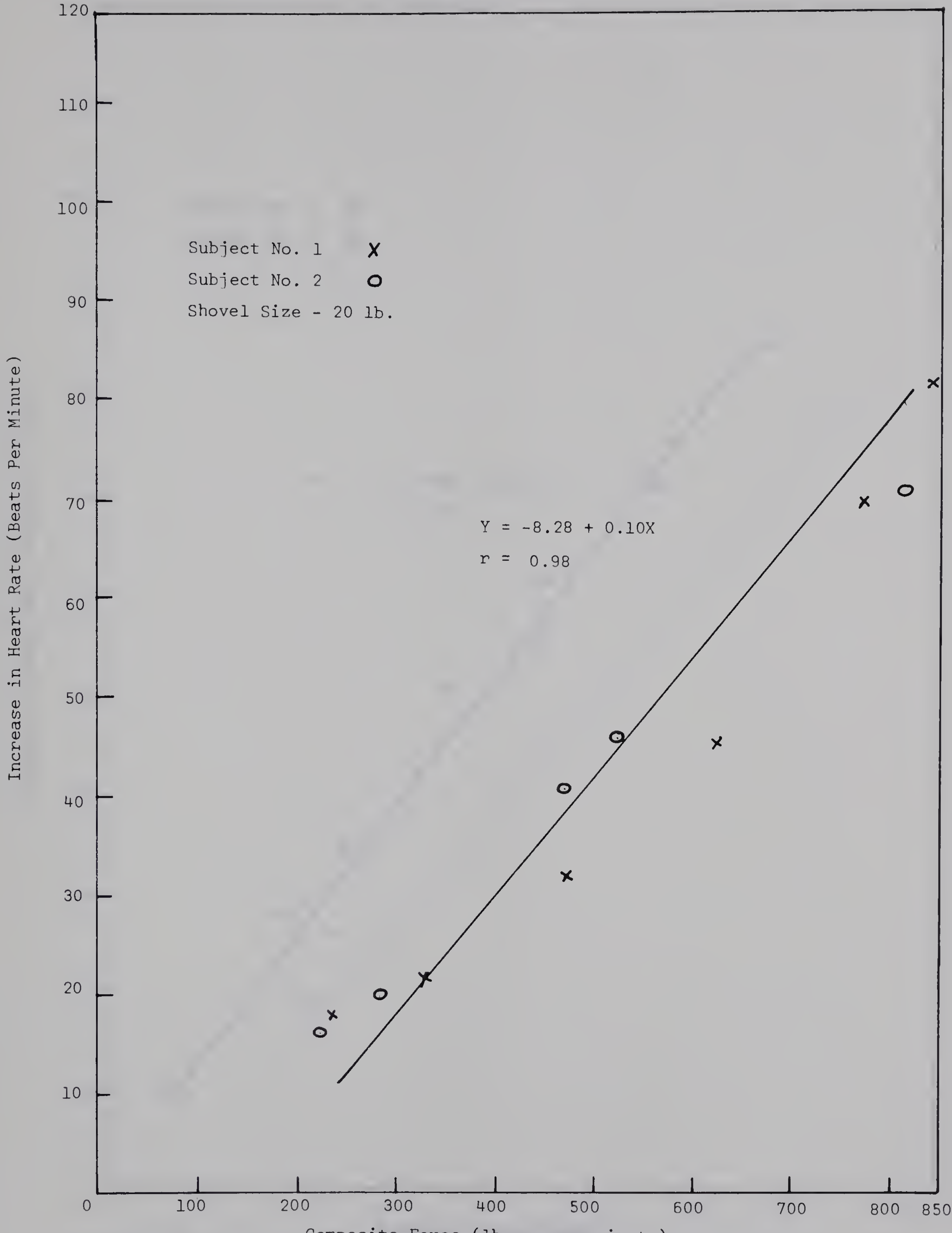


Figure 28: Regression of composite force on increase in heart rate for shovelling task.

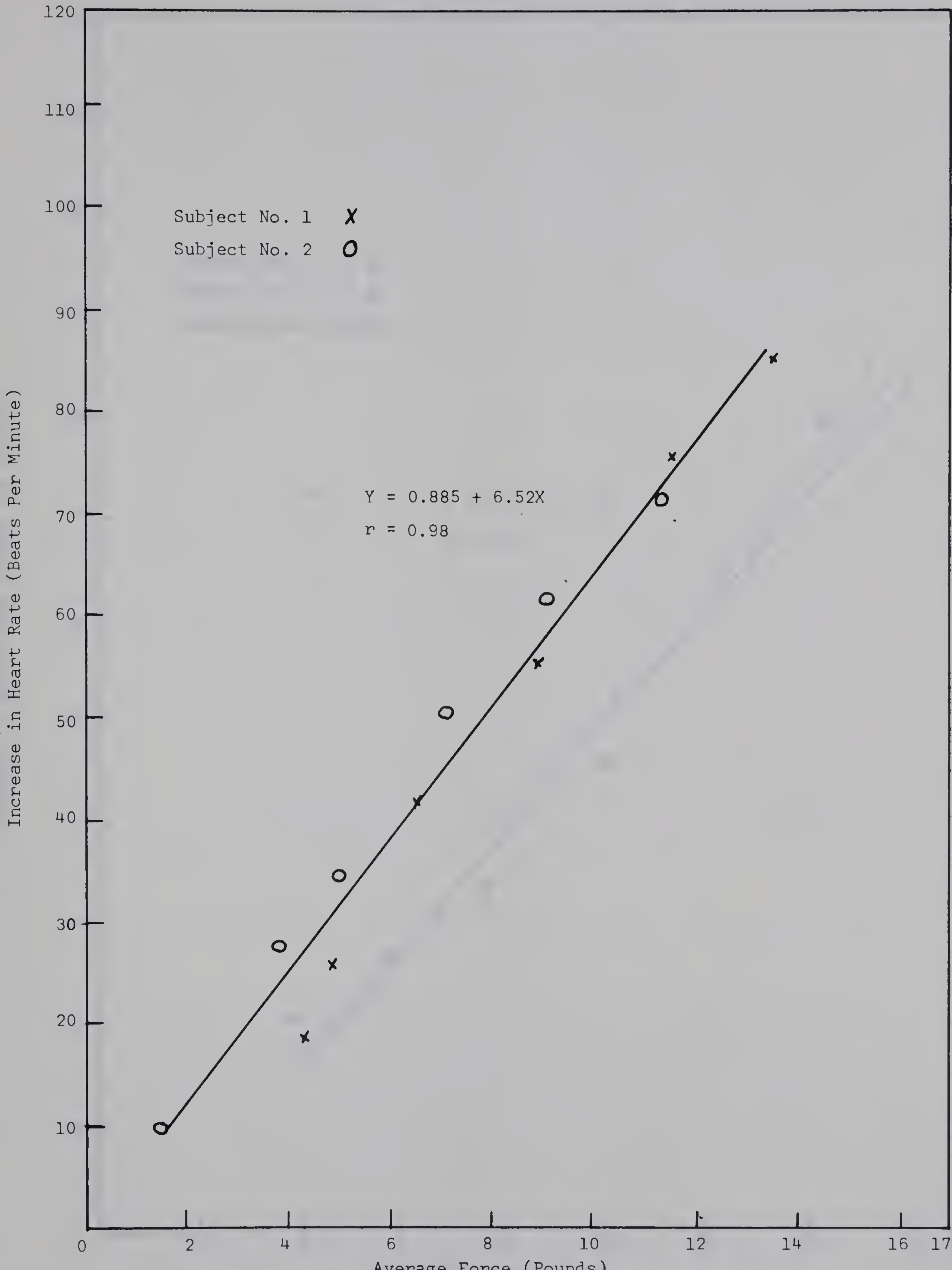
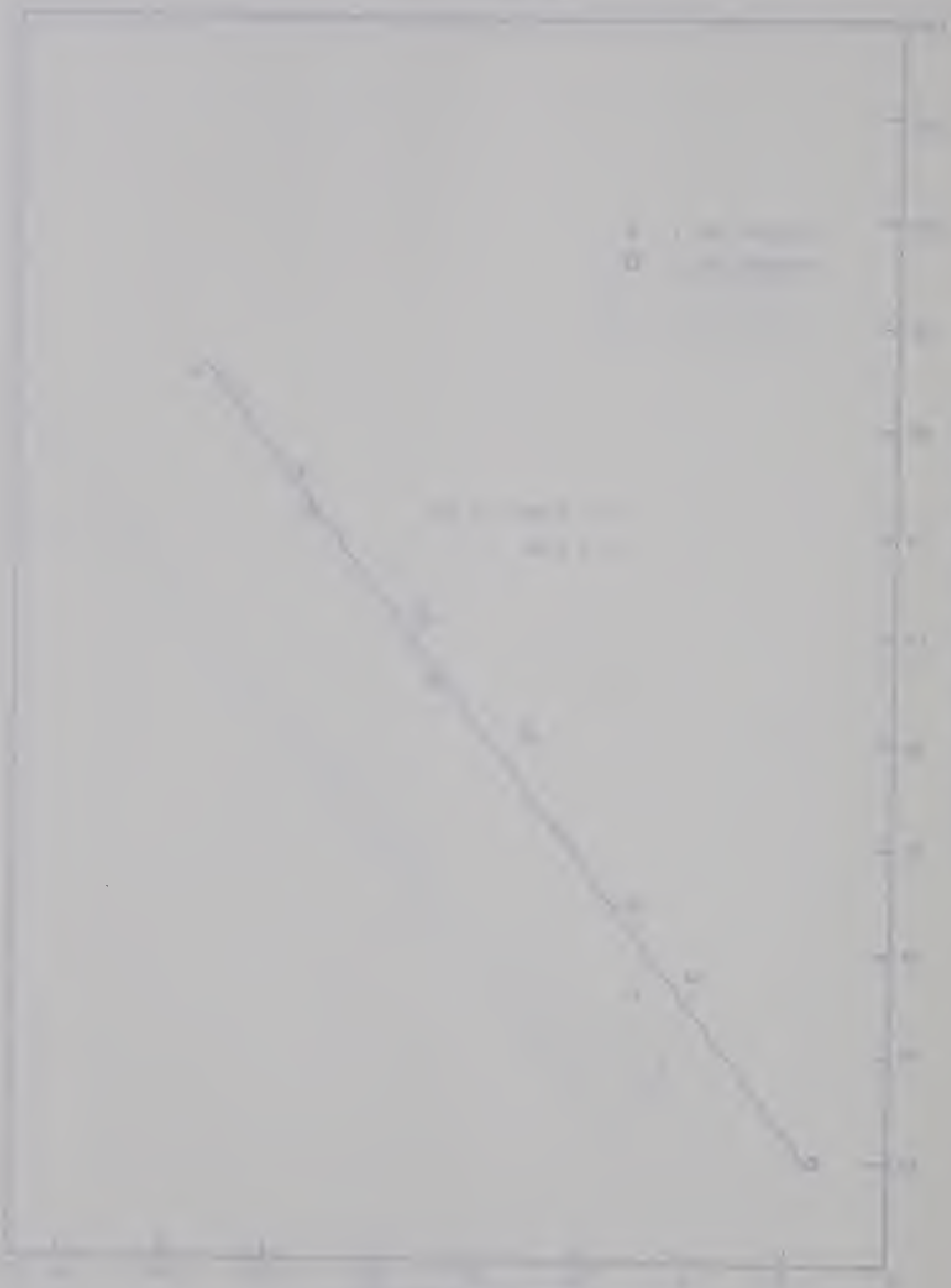


Figure 29: Regression of average force on increase in heart rate for hacksawing task.



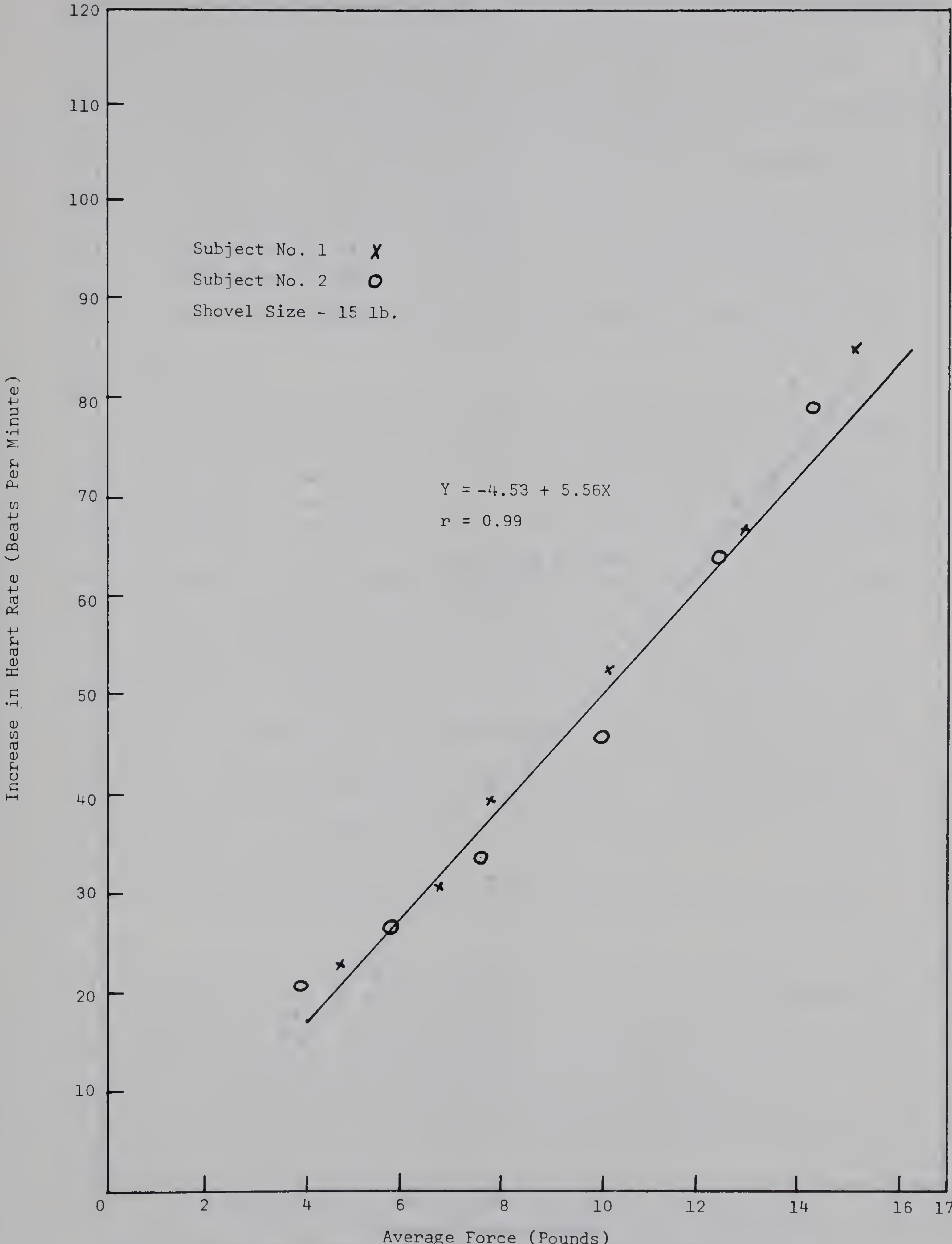
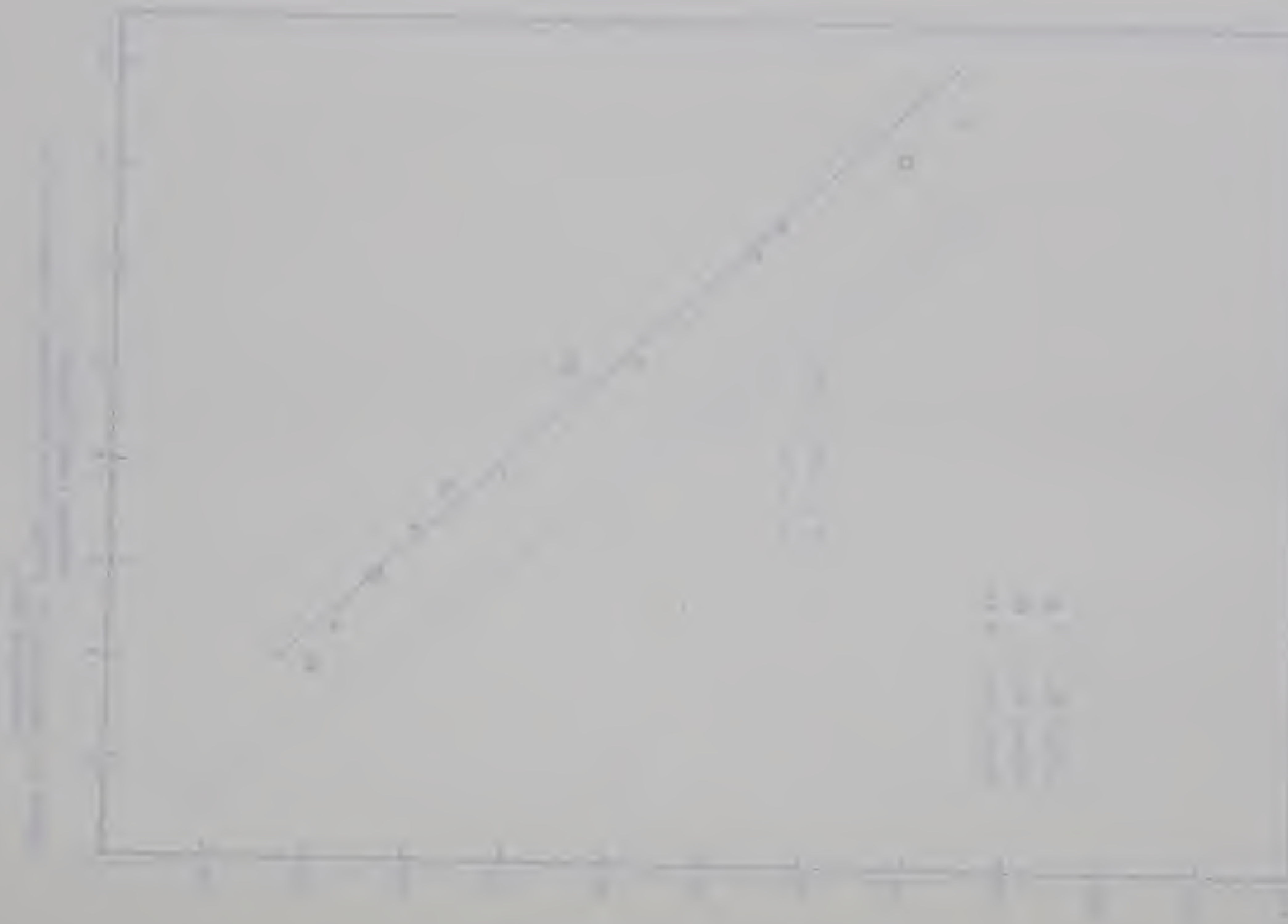


Figure 30: Regression of average force on increase in heart rate for shovelling task.



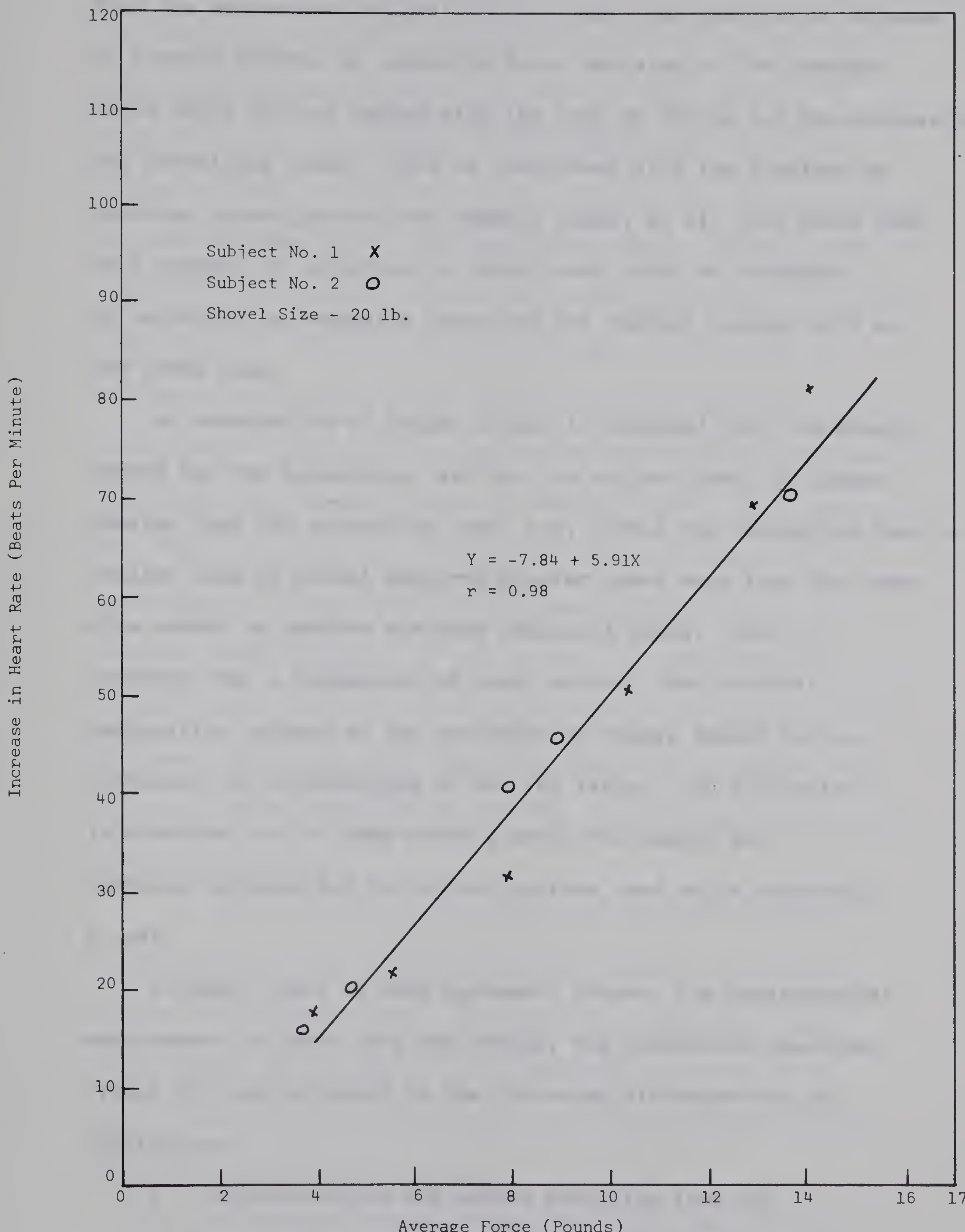


Figure 31: Regression of average force on increase in heart rate for shovelling task.

From the regression analysis, it is clear that heart rate increase is closely related to composite force and also to the average force which in turn varies with the pace or rating for the hacksawing and shovelling tasks. This is consistent with the findings of previous investigators; for example Yoder, et al, (40) found that 66.0 percent of variation in energy cost could be explained by variation in composite force for one subject working with an arm crank task.

An examination of Tables 11 and 12 revealed that the energy demand for the hacksawing task for the subject used, is always greater than the shovelling task, and, within the shovelling task, a smaller size of shovel required greater heart rate than the large size shovel to produce the same composite force. This is evidence that a comparison of tasks exists. One possible explanation related to the variation of energy demand is the different job difficulties of the two tasks. Job difficulty is dependent on the body members used, the weight and distance involved and the motion patterm used while performing a task.

Although there is good agreement between the physiological measurement of heart rate and rating, the prediction equations (Table 10) are subjected to the following discrepancies and limitations:

1. Inconsistencies and errors resulting from the personal judgement of the observer while rating.
2. Lack of correlation between the performance rating values of the two observers.

A force platform would appear to provide a means of eliminating the above discrepancies and limitations, and, moreover, it may provide an objective method of prediction of an operator's performance and physiological energy requirement for a task. Composite force as measured by force platform combines factors of operator performance and factors which retard (job difficulty) operator's performance. Composite force includes all the forces necessary for activities and for necessary body movements. Within the limitation of the design of the experiments, it can be concluded that there is a good correlation between increase in pulse rate and composite force or average force. This suggests that with an assessment of composite force or average force, physiological energy demand can be predicted for all of the practical jobs discussed in this study. An important extension of this study in addition to replication will be needed to find different regression equations for a variety of practical jobs. This will permit the prediction of the energy requirements under specific conditions.

Throughout the analysis, the product moment correlation coefficients are determined to find the degree of linearity of best fit straight lines. In almost all the cases, with the variables of interest, this coefficient is found to be high. Several factors which might have been operating to give these high correlations may be:

1. The number of subjects selected (two) constitutes a very small sample.
2. Calibration of the force platform was done by static weight loading.
3. Frictional forces, developed at the ball joints of transducers.

CHAPTER V

SUMMARY AND CONCLUSION

The purpose of this investigation was to determine the relationship of heart rate and the rating (pace or speed) of the subjects engaged in specified tasks. Another consideration was to investigate the suitability of the force platform as a means of measuring the operator's performance in relation to heart rate of the subjects. The specified selected tasks were hacksawing and shovelling.

Within the limitations of this investigation, the following inferences can be drawn from the experimental results:

1. There is a corresponding increase in working heart rate with an increase in rating for both the tasks.
2. The individual's working heart rate is linearly related to rating for the two tasks.
3. Increase in heart rate above the resting level is linearly related to rating for the two tasks. There is a physiological cost difference between the two tasks.
4. The linear relationships between increase in heart rate and rating could be utilised to find the extent of strain which might result in fatigue.

5. There is a corresponding increase in heart rate with an increase in force.
6. There is a linear relationship between increase in heart rate and composite or average force.
7. The regression analysis reveals that the increase in heart rate for the hacksawing task is greater than for the shovelling task for the same composite or average force.

On the basis of this investigation , it is believed that the present performance rating scale would be possibly more realistic if it were based on a physiological measurement like heart rate. Such a measure would be more objective and scientific than the present method of estimation of performance rating. Further, it is believed that the use of force platform measurements in relation to physiological measurements of heart rate to determine job difficulties and operator's performance, would be more objective and scientific.

BIBLIOGRAPHY

1. Astrand, Irma . Physiological Methods For Estimating The Physical Work Capacity In Workers, Especially Of The Older Age. Ergonomics, Vol. 1, No. 2, Feb. 1958. 129-136.

2. Astrand, I. Aerobic Work Capacity In Men and Women With Special Reference To Age. Acta Physiol. Scand., 49, Suppl. 169, 19 pp.

3. Barany, J.W. and R.G. Whetsel. Construction Of A Portable Force-Platform For Measuring Bodily Movements. Developed In Conjunction With National Science Foundation Grant G17738.

4. Barany, J.W. The Nature Of Individual Differences In Bodily Forces Exerted During A Simple Motor Task. The Journal of Industrial Engineering, Vol. 14, No. 6, Nov. - Dec. 1963. 332-341.

5. Barany, James W., Use Of Force Platform For The Study Of Hemiplegic Gait . Paper presented at the American Society for Engineering Education, Annual Meeting, June 22-26, 1964. University of Maine, Maine, U.S.A.

6. Barnes, R.M. Motion And Time Study: Design And Measurement Of Work, Fifth Edition . John Wiley and Sons, New York, 1963.

7. Barnes, R.M. Measuring Work By Physiological Methods. Proceedings International Conference, American Institute of Industrial Engineers, Sept. 23 - 25, 1963, New York, U.S.A.

8. Booyens, J. and G.R. Harvey. The Pulse Rate As A Means Of Measuring Metabolic Rate In Man, Canada. J. Biochem.Physiol. 38, 1960.

9. Christensen, E.H. Speed of Work, Ergonomics, Vol. 5, No. 1, January 1962. 7-14.

10. Cotes, J.E. and F. Meade The Energy, Expenditure, and Mechanical Energy Demand In Walking. Ergonomics, Vol. 3, No. 2, April 1960. 97-120.

11. DeJong, J.R. Speed Of Work And Machines - Ergonomical Aspects. Ergonomics, Vol. 5, No. 1, January 1962. 15-24.

12. Dupis, H. Effect Of Tractor Operation On Human Stresses. Agric. Engng., Vol. 40, September 1959. 510-519.

13. Elftsman, H., The Measurement Of The External Force In Walking. Science, 88, 1938. 152-153.

14. Elliott, G.M. Personal Correspondence. Physical Education Department, University of Alberta.

15. Esamy, M.L. and R.J. McGinty. Measurement Techniques Of Peak Human Stresses In And Around The Farmstead. Agric. Engng., Vol. 43, No. 11, November 1962. 644-647.

16. Greene, J.H. The Design And Initial Evaluation Of A Force Platform For Measuring Human Work. Unpublished doctoral dissertation, Iowa State University 1957.

17. Greene, J.H. and W.J.M. Morris. The Force-Platform: An Industrial Tool. Journal of Industrial Engineering, March-April, 1958.

18. Greene, J.H. and W.J.M. Morris. The Design Of A Force Platform For Work Measurement. Journal of Industrial Engineering, July-August, 1959.

19. Hodges, T.O. and M.L. Esmay. Human Energy Expended In Handling Baled Hay And Straw. Agric. Engng., Vol. 41, No. 8, August 1960. 502-505.

20. Karpovich, P.V. Physiology Of Muscular Activity, 4th Edition, Saunders Company, London 1953.

21. Lauru, L. Physiological Study Of Motions. Advance Management, 22(3) 1957.

22. Lauru, L. The Measurement of Fatigue. The Manager, 22, 1954.

23. Malhotra, M.S., J. Sen Gupta and R.M. Rai. Pulse Count As A Measure Of Energy Expenditure. J. Appl. Physiol., 18, 1963. 994-996.

24. Marks, M. and G. Herschberg. Analysis Of The Hemiplegic Gait. Annuals Of New York Academy Of Sciences, 71, 1954.

25. Martiz, J.S., J.F. Morrison, J. Peter, P.B. Strydom and C.H. Wyndham. A Practical Method Of Estimating An Individual's Maximal Oxygen Intake. Ergonomics, Vol. 4, No. 2, April, 1961. 97-122.

26. Molbech, S. and E. Asmussen. Speed Of Work As A Measure Of Work Intensity. Ergonomics, Vol. 5, No. 1, January 1962. 67-70.

27. Nadler, G. Work Design. Richard D. Irwin, Inc., Homewood, Illinois, 1963.

28. Payne, A.H., W.J. Slater and T. Telford. The Use Of Force Platform In The Study Of Athletic Activities-A Preliminary Investigation. Ergonomics, Vol. 11, No. 2, March 1968. 123-143.

29. Poulsen, E.E. and Asmussen. Energy Requirement of Practical Jobs From Pulse Increase and Ergometer Test. Ergonomics, Vol. 5, No. 1, January 1962. 33-36.

30. Russell, D.G., Force Platform Operating Instructions, Department of Agricultural Engineering, University of Alberta, September, 1965. (Mimeograph).

31. Russel, E.N. An Analysis of Force-Time Characteristics Of Selected Sprint Starts In Swimming. Unpublished M.Sc. Thesis, University of Alberta, 1967.

32. Schertz, C.E. Human Energy Expenditure For Picking Oranges. J. Agric. Engng. Res., Vol. 12, No. 4, December 1967. 281-284.

33. Sharkey, B.J., J.F. Macdonald and L.G. Corbridge. Pulse Rate and Pulmonary Ventilation As Predictions Of Human Energy Cost. Ergonomics, Vol. 9, No. 3, 1966. 223-228.

34. Shepard, R.J. The Prediction Of Maximal Oxygen Consumption Using A New Progressive Step Test. Ergonomics, Vol. 10, No. 1, 1967. 1-16.

35. Smillie, K.W. STATPACK 1: AN APL Statistical Package, Publication No. 9, Department of Computing Science, University of Alberta, January 1968.

36. Steel, R.G.D. and J.H. Torrie. Principals and Procedures of Statistics. McGraw-Hill Book Co., Inc., New York, 1960.

37. Whitney, R.J. The Strength Of The Lifting Action In Man. Ergonomics, Vol. 1, No. 2, 1958. 101-128.

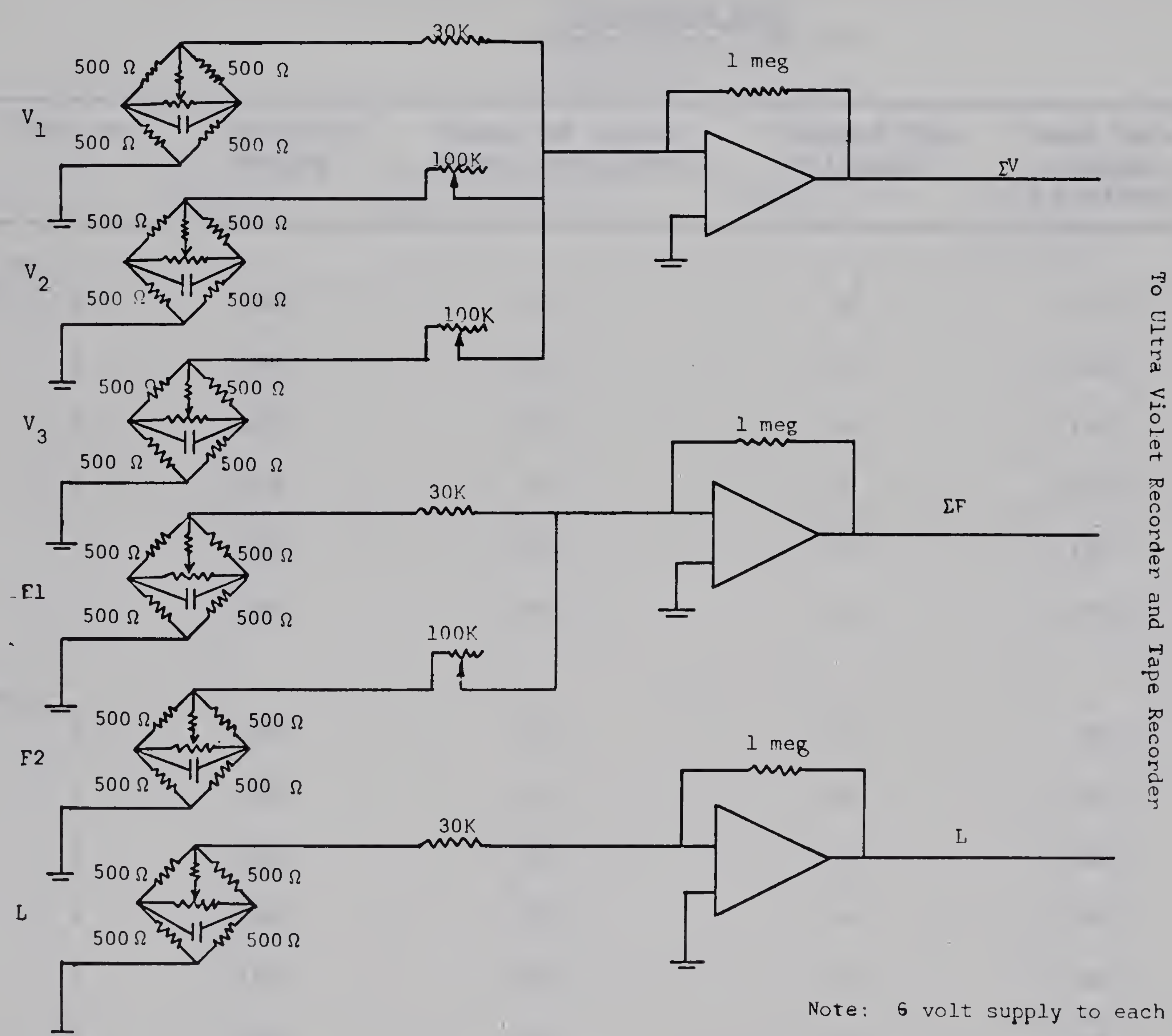
38. Wyndham, C.H., N.B. Strydom, J.F. Morrison, C.G. Williams, G. Bredell, J. Peter, H.M. Cooke and A. Joffe. The Influence Of Gross Body Weight On Oxygen Consumption And On Physical Working Capacity Of Manual Labourers. Ergonomics, Vol. 6, Number 3, July 1963. 275-286.

39. Wyndham, C.H., J.F. Morrison, C.G. Williams, A. Heyns, E. Margo, A.N. Brown and J. Astrup. The Relationship Between Energy Expenditure And Performance Index In The Task Of Shovelling Sand,Ergonomics, Vol. 9, No. 5, September 1966. 371-378.

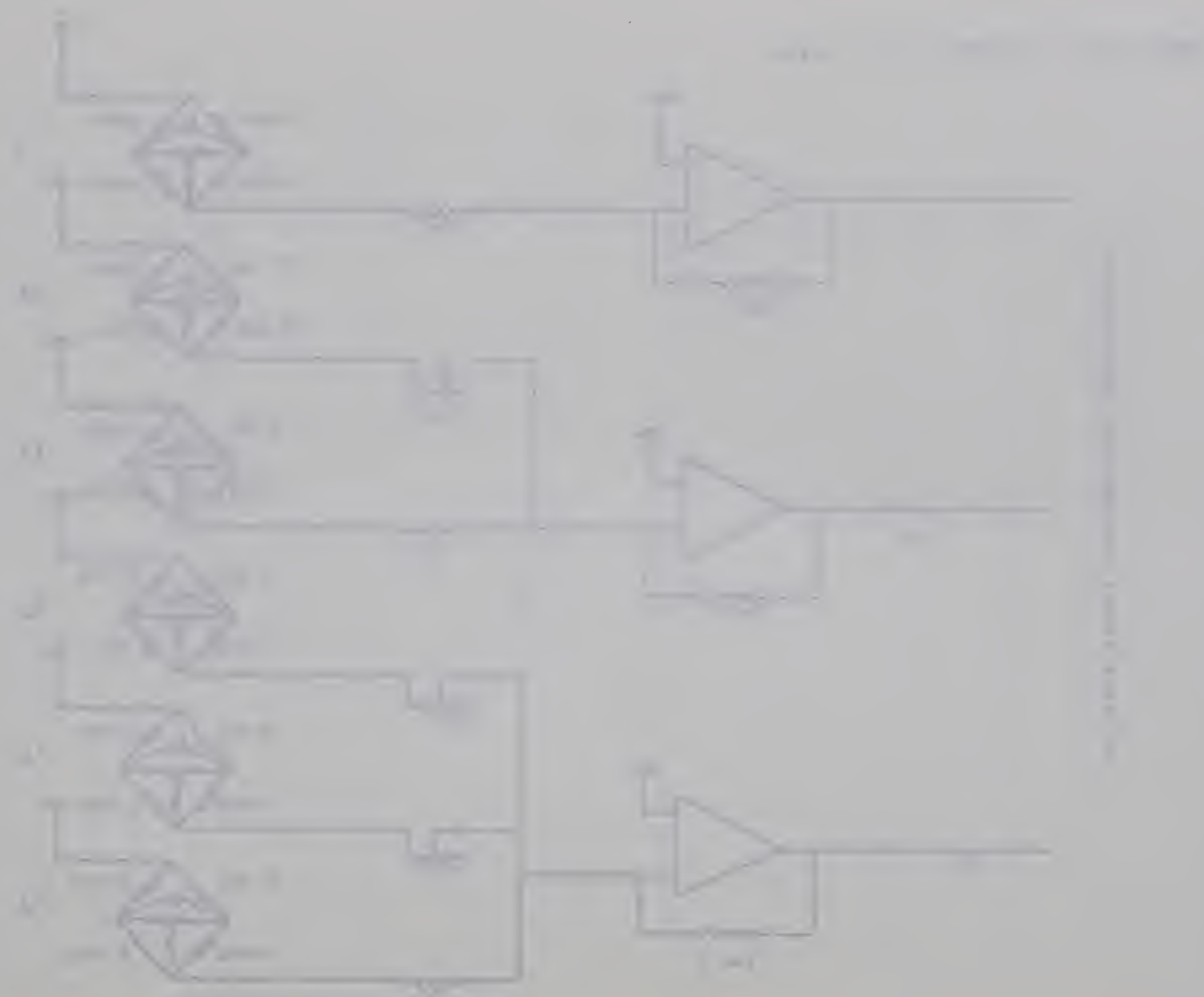
40. Yoder, T., J. Barany and A.H. Ismail. A Physiological Evaluation Of A Portable Force Platform. Report Based Upon A M.S.I.E. Thesis At Purdue University, Indiana.

APPENDICES

APPENDIX A: CIRCUIT DIAGRAM FOR AMPLIFICATION AND SUMMATION OF FORCES.



Note: 6 volt supply to each bridge.



APPENDIX B: SUMMARY OF DATA COLLECTED .

Shovelling Task
(shovel size - 15 lb)

	Test No.	Estimated Rating	Number of shovel throws per minute	Elapsed Time (minutes)	Heart Rate during 3-4 minute	Total Vertical lb-second	Total Frontal lb-second
Subject No. 1 (Rest Heart Rate 87)							
	1	60	15	4	110	915.00	420.00
	2	95	21	4	118	1317.00	617.00
	3	110	27	4	127	1690	785.00
	4	145	33	4	140	2250	960.00
	5	160	40	4	154	2870	1160.00
	6	190	47	4	172	3380	1360.00
Subject No. 1 (Rest Heart Rate 74)							
	1	60	14	4	95	850.00	400.00
	2	90	20	4	101	1250.00	570.00
	3	115	25	4	108	1710.00	710.00
	4	140	32	4	120	2245.00	930.00
	5	160	40	4	138	2760.00	1090.00
	6	175	47	4	148	3280.00	1260.00

APPENDIX B: Continued.

Shovelling Task
(Shovel size - 20 lb)

	Test No.	Estimated Rating	Number of shovel throws per minute	Elapsed Time (minutes)	Heart Rate during 3-4 minute	Total Vertical lb-second	Total Frontal lb-second
Subject No. 1 (Rest Heart Rate 88)							
	1	60	10	4	106	880.00	350.00
	2	85	14	4	110	1230.00	490.00
	3	110	20	4	120	1760.00	700.00
	4	140	26	4	139	2340.00	910.00
	5	160	30	4	158	2700.00	1050.00
	6	180	32	4	170	3180.00	1220.00
Subject No. 2 (Rest Heart Rate 72)							
	1	70	10	4	88	800.00	400.00
	2	90	13	4	92	1050.00	520.00
	3	120	22	4	113	1700.00	740.00
	4	145	25	4	118	2080.00	985.00
	5	180	33	4	143	2952.00	1420.00

APPENDIX B: Continued. Hacksawing.

	Test No.	Estimated Rating	Average Calculated time for 10 Strokes (minutes)	Elapsed Time (Minutes)	Heart Rate During 3-4 minute of working	Total Frontal lb-sec.
Subject No. 1 (Rest Heart Rate 89)						
	1	80	0.17	4	108	1052.00
	2	85	0.14	4	115	1160.00
	3	100	0.13	4	131	1578.00
	4	110	0.10	4	145	2120.00
	5	130	0.08	4	166	2800.00
	6	150	0.07	4	176	3268.00
Subject No. 2 (Rest Heart Rate 72)						
	1	45	0.33	4	82	360.00
	2	70	0.20	4	100	920.00
	3	100	0.14	4	107	1200.00
	4	110	0.13	4	123	1720.00
	5	130	0.09	4	132	2200.00
	6	150	0.08	4	142	2720.00